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Surface Layer Stability Transition Research, Minimum Time Delay from Sunrise: 2001 March Case Study

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Preface

In 2001, the U.S. Army Research Laboratory, Meteorological-sensors Integration Team, conducted a series of three field tests in the southwestern desert of the United States. The purpose was to identify, characterize, and exploit repeatable atmospheric patterns found in the lowest layer of the Boundary Layer, the Surface Layer. The repeatable pattern selected was the Surface Layer Stability Transition. Each field test was timed with the purpose of validating a seasonal extreme in the annual morning Stability Transition (ST) timing cycle. Within this publication, the authors present the key results and understandings gained from the 2001 March Equinox-Atmospheric Surface Layer Field Test, which was conducted by the Meteorological-sensors Integration Team at White Sands Missile Range, NM.

Each field test serves as a building block in the overall goal of modeling the ST. The information gained from these field tests has three fundamental links to the U. S. Army and to the military in general:

1. This research expands on U.S. Army Chief of Staff Shinseki's vision.
2. The knowledge of exploitable atmospheric characteristics, such as an ST, enhances electro-optical weapon effectiveness and efficiency.
3. The accurate ST forecasts provide crucial initializing information for atmospheric models that forecast chemical and biological weapon effects, as well as transport and diffusion effects.

Acknowledgments

Appreciation is extended to the Meteorological-sensors Integration Team (MIT) members for their successful execution of the 2001 March Equinox-Atmospheric Surface Layer Field Test. The MIT Team members included: Robert Brown, Edward Creegan, Doyle "Scott" Elliott, Alfred Gutierrez, David Quintis, Gail Vaucher (Team Leader) and Jimmy Yarbrough. Also, appreciation goes to Ms. Nancy Fudge, for her efforts in linking the remote site field test activities with the demands of the standard work hour routines.

Executive Summary

U.S. Army Chief of Staff Shinseki stated that his U.S. Army vision was to see first, act first, kill first. In GovExec.com's *Daily Briefing*, Freedberg Jr. wrote that the most powerful, accurate and quickest weapon on the planet is the laser. Both military concerns have one major hurdle, "seeing" through the atmosphere. The Surface Layer Stability Transition (SLST) Research has been investigating naturally occurring atmospheric patterns that enhance or detract from the successful "seeing" mission. These same Stability Transition (ST) patterns also provide knowledge of when the effects of chemical and biological weapons will shift from foe (toxic concentrations in a limited area) to friendly (non-toxic concentrations in a broad area), and vice versa. Likewise, initializing the convective Boundary Layer growth phase (ST) impacts civilian and military Atmospheric Dispersion/Diffusion Model accuracy. For the military, knowing when a smoke screen will "clear", for example, could prove to be a significant strategic advantage on a battlefield.

In 2001, the Meteorological-sensors Integration Team conducted the first of three field tests with the primary purpose of characterizing, modeling and exploiting repeatable patterns in the lower portion of the Atmospheric Boundary Layer, the Surface Layer. The repeatable pattern that focused the investigation was the morning Stability Transition (ST) period, or Neutral Event (NE). The 2001 March 19–22 time period was specifically selected based on a forecasted minimal time interval between the local Sunrise and an Ideal case ST. The two subsequent field tests addressed the maximum (June 2001) and the second minimal (September 2001) time interval between the local Sunrise and an Ideal case ST. These latter Tests will be documented individually in future technical reports.

To characterize the repeatable ST pattern, two perspectives were pursued in the measurements and the analyses: a Eulerian and a quasi-Lagrangian approach. The ongoing ST modeling effort was enhanced by the validation point provided by the 2001 March Equinox-Atmospheric Surface Layer Test for the Ideal NE Forecast Model. While the exploitation of the ST is beyond the purpose of this technical report, the information documented here does serve as a useful building block in support of that primary goal.

1. Introduction

1.1 U.S. Army Interest in Atmospheric Stability Transition Research

Atmospheric Stability Transition (ST) Research links to military interests in at least three arenas. In the July 2002 *Army Materiel Command Newsletter*, U.S. Army Chief of Staff Shinseki stated that his vision for the U.S. Army was "to see first, act first, kill first...To see first, we must have persistent and pervasive intelligence-gathering capabilities" (Burlas, 2002). The atmosphere is one of the major hurdles retarding the efficiency of "seeing first." The Boundary Layer Exploitation Task-Surface Layer Stability Transition Research has been investigating naturally occurring atmospheric patterns that enhance or detract from the successful "seeing first" capability. Under favorable atmospheric conditions, target identification is potentially done quicker, making the last two actions of the Shinseki's U.S. Army vision more efficient and effective.

Sydney Freedberg Jr. wrote in his GovExec.com *Daily Briefing*, that the most powerful, most accurate and quickest weapon on the planet, the laser, has one major obstacle, the weather (Freedberg, 2001). To quantify the atmospheric impact on this, or any other electro-optical (EO) weapon, one needs to understand a parameter called "seeing". To an astronomer, "seeing" is the arc second or angle occupied by the star image at the full-width and half-maximum of its intensity profile, as viewed from a specific point in the atmosphere (Businger et al., 2002). "Seeing" improves or degrades with changes in the atmospheric optical turbulence strength and location as quantified by profiles of the refractive index structure function C_n^2. The SLST Research grew out of EO propagation research, and now serves as a building block for understanding and forecasting the naturally occurring atmospheric cycles that are both favorable and non-favorable for the laser and any subset of this weapon type.

Finally, a significant urban warfare hazard is the release of chemical and biological weapons. The atmosphere, specifically the Boundary Layer convection, can enhance or detract from the weapon's effectiveness. From a military perspective, knowledge of a ST means knowledge of when the chemical and biological weapon's effect will shift from foe (toxic concentrations in a limited area) to friendly (non-toxic concentrations in a broad area), and vice versa (Angevine et al., 2001).

Likewise, initializing the convective Boundary Layer growth phase (the ST) is a primary interest to civilian and military Convective Boundary Layer and Atmospheric Dispersion/Diffusion Modelers. Model results often reflect the initial input accuracy. For the military, knowing when a smoke screen will "clear", for example, could prove to be a significant strategic advantage on a battlefield. Thus, the ST pattern ties to both

military and civilian applications (Angevine et al., 2001). Additional civilian interests will be described in the next section.

1.2 Civilian Interest in Atmospheric Stability Transition Research

The Atmospheric Boundary Layer behavior during the period between the fully developed convection of mid-day and the stable conditions of the nocturnal Boundary Layer is poorly understood, but is of interest in several fields, including chemical and pollutant modeling (Grimsdell and Angevine, 2002). Grimsdell and Angevine focused their work on the afternoon ST in agricultural environments. However, their assessment regarding the poor understanding is also true for the morning Surface Layer ST in a desert environment.

Finally, in the June 2002 *Bulletin of the American Meteorological Society*, Businger et al., describe the unique weather forecasting requirements for the highly technical stellar viewing at Hawaii's Mauna Kea Observatories. Clear air turbulence in both the free atmosphere and in the Boundary Layer were flagged as causes for image distortion and blurring for their ground-based telescopes. Forecasting the observing quality for seeing parameters accurately is a key factor in the successful scheduling of these very expensive civilian optical and infrared instruments. Knowing when the atmospheric impact would be minimal, such as during a ST, would be a significant improvement and enhancement for the astronomical community (Businger et al., 2002).

1.3 Purpose and Overview

This document is the first of three technical reports stemming from a study with the governing purpose of characterizing, modeling and exploiting the lower portion of the Atmospheric Boundary Layer, the Surface Layer. The specific Surface Layer activity being investigated was the ST. This report presents the key results and new understandings gained from the 2001 March Equinox-Atmospheric Surface Layer Field Test conducted by the Meteorological-sensors Integration Team (MIT) of the U.S. Army Research Laboratory (ARL). This Test was executed at the Thompson Tower site (Lat: 32.35, Long: –106.47), in White Sands Missile Range (WSMR), NM. One of the primary goals of this field test was to validate the proposed Seasonal Algorithm used in forecasting the exact time of the morning ST (Vaucher and Endlich, 1995). A mechanism for describing the unique nature of the Surface Layer is turbulence (Tatarski, 1961). The dynamics of turbulence affects the Surface Layer stability, which impacts the U.S. Army's ability to function efficiently. Thus, the fruit of this investigation feeds both the scientific goals of better understanding the evolution of the Atmospheric Boundary Layer, and the U.S. Army's need to improve their efficiency by exploiting the natural character/patterns of the Atmospheric Boundary and Surface Layers.

1.4 Background of the Stability Transition Study

The initial ST study was funded by the Atmospheric Science Laboratory and conducted at the U.S. Army-owned High Energy Laser Systems Test Facility (HELSTF), NM in the mid-1990s (USASL Contract). This study was prompted by an operational need to minimize the impact of atmospheric optical turbulence (AOT) on the High Energy Laser (HEL) when propagating along a 1 km path. Based on observations, the HELSTF meteorologists noted that twice a day the AOT would drop to a minimum. These AOT minima correlated closely with the morning and evening STs.

Over time, ARL meteorological operational researchers developed a "rule of thumb" approach for forecasting the morning and evening STs. This "rule of thumb" suggested that a minimum amount of AOT occurred when the atmosphere was neither stable, nor unstable, and that such a "Neutral Event (NE)" occurred 60 min after sunrise, and 40 min before sunset. While the "rule of thumb" was able to yield a ballpark accuracy, the high cost of HEL testing quickly demanded a more precise forecast. Thus, a more rigorous investigation began.

In 1994, Vaucher and Endlich published results from the first of two significant studies. According to their 2-month study, the average occurrence of the morning NE was about 70 min after sunrise. The time difference between sunrise and the associated NE ranged between 40 and 133 min after sunrise. The evening NE occurred an average of about 60 min before sunset, with a Sunset-NE time difference ranging between 98 and 12 min before sunset (Vaucher and Endlich, 1994). They also noted that there was an implied trend in their statistical findings. Consequently, a follow-on study was pursued.

In 1995, Vaucher and Endlich published the results from a 16-month AOT NE study conducted at HELSTF, NM. Recognizing the local heat flux as the primary contributor to AOT, the authors isolated three variables (Sunrise/Sunset time, Delta-T and Insolation) related to the heat flux, and observed their relationship to the NE over a 1 km desert path. The 16 m minus 2 m Temperature (T) difference (Delta-T) was examined at the start and end of the sampling path. Results reported near-surface, slightly dry adiabatic conditions present during a NE. The NE-insolation values showed that the ranges of insolation magnitudes at the Sunrise-NE were about twice those sampled at the Sunset-NE. This observation was explained as a function of the sun's elevation.

The most significant discovery of the 1995 study, with respect to ST forecasting, came while overlaying local sunrise and NE times. The minimum average time difference between local sunrise and NE was reported in the Equinox months. The maximum monthly time difference average occurred in the Solstice months. Vaucher and Endlich theorized that the skewed diurnal heating-cooling cycle of the solstice periods generated strong near-surface temperature inversions that delayed the transition into the near-dry adiabatic atmosphere required for a NE. During the Equinox, the 24-h heating-cooling

cycle was nearly equal. Therefore, minimal time was needed for the day or nighttime atmosphere to transition into the near-dry adiabatic environment (Vaucher and Endlich, 1995).

Figure 1 displays the seasonal effect discovered by Vaucher and Endlich. In this figure, the Sunrise NE (SRNE) Rule of Thumb Forecast is contrasted with the actually observed NE time.

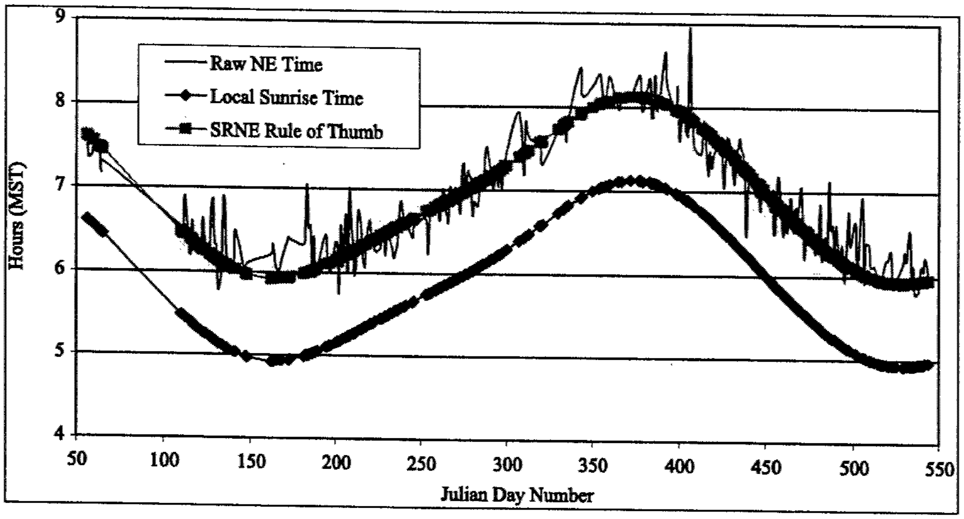

Figure 1. Local Sunrise, SRNE Rule of Thumb, and NE Times, 1994 February-1995 June (Raw Data).

To display the oscillation more plainly, figure 2 shows the "rule of thumb", the monthly averaged NE time, and the actual NEs.

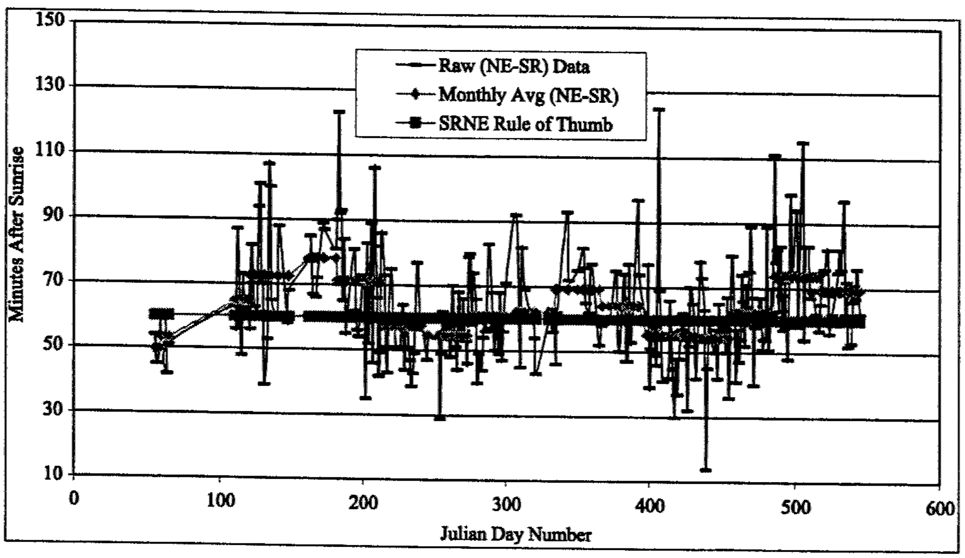

Figure 2. SRNE Rule of Thumb, Raw and Monthly Averaged NEs, 1994 February-1995 June.

Removing the actual data, figure 3 shows the annual cycle of average NE by month. Note the Equinox NE minima (September, March) and the Solstice NE maxima (June, December). The first minimum is ignored due to the lack of data for the initial month.

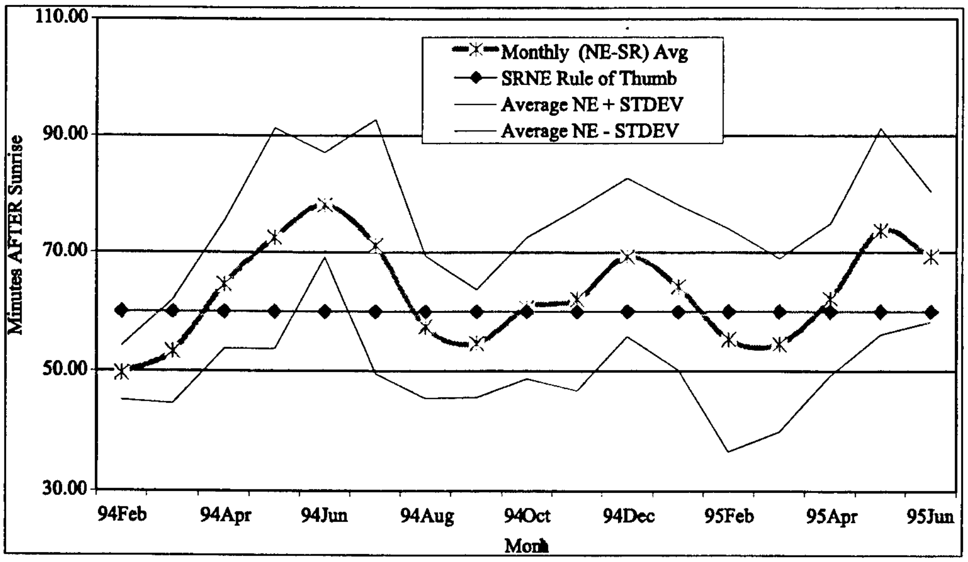

Figure 3. Monthly Averaged Sunrise Neutral Event Time Differences, 1994 April-1995 June.

Based on the 16-month study, Vaucher and Endlich updated the Rule of Thumb NE Forecast approach by introducing a seasonal correction curve. The coefficients produced by the Fourier Waveform Analysis can be found in their 1995 Battlefield Atmospheric Conference paper (Vaucher and Endlich, 1995).

The 16-month study left some unanswered questions:

1. Are the updated Rule of Thumb NE Forecast algorithms site specific? What about a non-desert environment? What about other latitudes?

2. Is the seasonal oscillation real or a coincidence?

3. The current model works under Ideal atmospheric conditions. What about under Non-ideal conditions (see section 1.6)?

ARL addressed some of these questions during the FY01 field tests. First, however, this report examines the ST character and the Ideal versus Non-ideal atmospheric conditions.

1.5 Character of the Stability Transition

The ST character is best understood by examining a full 24-h stability cycle. Figure 4 presents a "typical" diurnal pattern (a March Equinox AOT time series over a high elevation desert site in the southwestern United States) and can be used as a visualization tool for the following stability cycle description. Additional information on typical stability cycles can be found in *Meteorology for Scientists and Engineers* (Stull, 2000) and *An Introduction to Boundary Layer Meteorology* (Stull, 2001).

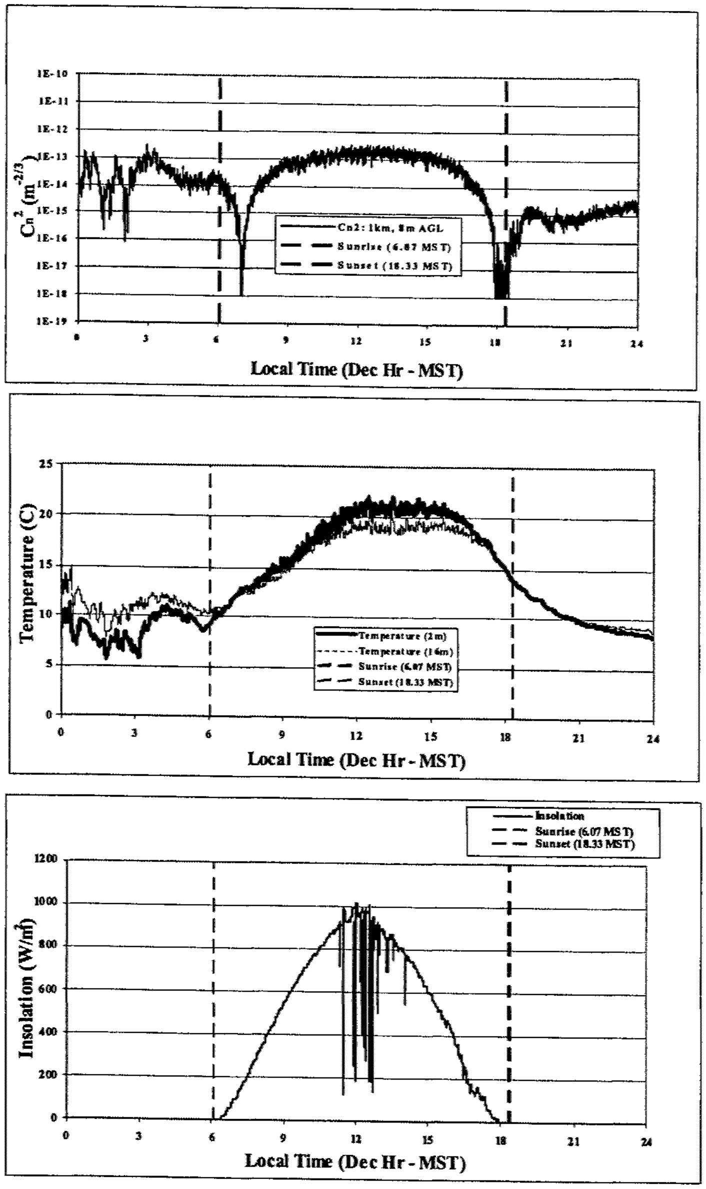

Figure 4. Coincident C_n^2, Temperatures, and Insolation Time Series along a 1–km path for 24 March 2001 at HELSTF, NM.

0000-Sunrise. Under clear skies, calm winds, and low ground moisture, the desert basin at 0000 hours Local Time is stably stratified. The coldest temperatures are at the lowest levels (Delta-T > 0). The heat flux is negative, and the AOT is a moderate-to-low level. Katabatic flow off neighboring mountains serves as a catalyst for overturning and mixing the nighttime stable atmospheric layers. The result is a mélange of density variations, which produces intermittent maxima of AOT. If winds decrease, AOT will return to the normal moderate-to-low level.

Sunrise occurs. The rays of sunrise start warming the ground, which radiates heat into the lowest atmospheric layer. The heat flux steadily increases, causing the stable

atmosphere to become isothermal and "neutral." C_n^2, coincidently, drops to a minimum. This is the morning, or Sunrise AOT NE.

Daytime. As the sun continues warming the ground throughout the morning, the neutral stability shifts into an unstable state. The heat flux is positive. The vertical temperature differences are now negative and C_n^2 increases. Atmospheric convection attempts to rebalance the unstable conditions by mixing the near surface warm air into the cooler air aloft. The persistent sun strengthens the unstable state, deepening the mixed layer. The constant mixing intensifies the atmospheric density variations and the AOT further increases. AOT reaches a peak around midday, or soon after.

The waning of the sun in the clear afternoon skies reduces the insolation and decreases the negative Delta-T magnitudes. Subsequently, AOT decreases. Just prior to sunset, the atmosphere briefly becomes near-dry adiabatic (neutral) and C_n^2 drops to a minimum. The heat flux goes to zero and the day's second NE takes place.

Sunset occurs. Civil, Military and Astronomical Twilights quickly evolve until there is the nighttime darkness. The previously warmed soil strongly emits the Solar Radiation absorbed during the daylight hours and cools rapidly. Delta-T becomes positive, confirming the presence of a stable atmosphere. Colder, heavier air, from the surrounding mountains and hills, drains into the valleys, serving as a mixing tool. The non-uniform radiative cooling and clear sky drainage flow creates an ambient mixing, which keeps the AOT at a moderate level throughout the night. The moderate AOT is punctuated by occasional, intermittent AOT maxima.

Within the diurnal cycle just described, the two primary NE times are clearly linked with the local sunrise and sunset. As the stable nighttime conditions transition to unstable daytime conditions, a Sunrise NE occurs. Likewise, as the unstable daytime evolves to a stable nighttime atmosphere, a Sunset NE occurs. Common to both scenarios is a period in which the atmosphere is near-dry adiabatic, exhibiting the least variations of C_n^2 along a horizontal and vertical path. The target of the SLST research is to successfully forecast the initial time for these transition events (Vaucher et al., 2003).

1.6 Ideal and Non-ideal Stability Transition Forecast Standards

Two distinct scenarios, Ideal and Non-ideal atmospheric conditions, were observed during the mid-1990 ST studies:

1. Ideal atmospheric conditions were defined as clear skies, low winds and low ground moisture.

2. Non-ideal atmospheric conditions included all other atmospheric traits, especially any cloud occultation of the sun during sunrise/sunset.

Local atmospheric conditions determined the ST duration. Under Ideal conditions, the transition was often less than 2 min. Ironically, the Ideal condition ST forecast (with

seasonal correction algorithms) produced the best results for the HELSTF, WSMR, NM site. In fact, one could accurately forecast to the minute when a Sunrise NE would occur 9 months in advance of the forecast, presuming that the day of validation had Ideal atmospheric conditions.

Forecasting for the Non-ideal atmospheric scenario was another story. First, the NE duration was anywhere from 1 min to over 20 min. In a future ARL technical report documenting the 2001 June Solstice-Atmospheric Surface Layer Test, evidence will be given to show that neutral atmospheric conditions can exist for at least 26 min. Another characteristic of Non-ideal scenarios was the generation of multiple NEs. Some major contributors to these Non-ideal NE conditions included:

1. Solar disc occultation during sunrise/sunset.
2. Sun ray obscuration after sunrise/before sunset.
3. The presence of local ground moisture.
4. The presence of non-standard local forcing (such as a frontal passage).

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2. Seasonal Algorithm Statistical Minimum Test

2.1 2001 March Equinox-Atmospheric Surface Layer Test Overview

The 2001 March Equinox-Atmospheric Surface Layer Test was conducted 19–22 March 2001 at the 100 ft Thompson Tower site, in WSMR, NM. The participants of the Test included the members of MIT, David Tofsted of ARL's Weather Exploitation Branch, and SFC DJ James. The Test Coordinator was Gail Vaucher. The three purposes of the Test, with each respective point-of-contact (POC), were:

(1) To be the first of three FY01 sampling sets aimed at verifying the maximum and minimum magnitudes of the Neutral Event Forecasting Model seasonal effects (POC: Gail Vaucher).

(2) To quantitatively characterize the desert atmospheric Surface Layer by studying the atmospheric lapse rate changes (Stability), wind currents, and insolation during the night-to-day transition period (POC: Doyle "Scott" Elliott).

(3) To assess the relationship between observed angle-of-arrival variance, as derived from collected imagery and scintillometer-measured C_n^2, in support of image modification code validation (POC: David Tofsted).

Prior to the field test execution, a 1 km scintillometer path from Thompson Tower was scouted using global positioning system (GPS) location sensors. The resulting path represented the most consistent desert terrain covering. A 4 m scaffolding was installed at both the start (Thompson Tower) and the end (Ammo Site) of this path. Reciprocal scintillometer sensors were assembled and mounted at the 4 m levels. The temporary housing for the computer equipment at the remote Ammo Site was provided by a Commercial Utility Cargo Vehicle with shelter (known locally as "the pig"). The power for the site was a mobile 20 kW generator. A mobile High Speed Trailer (HST) attached to hard power provided the equivalent for the Thompson Tower site. A manufacturer's delay in the arrival of purchased scintillometer computer cards prohibited local C_n^2 data acquisition during the test. However, all of the groundwork for the C_n^2 acquisition was in place.

Meteorological sensors included a 4 m TacMet II unit at Ammo Site, and two surface sensor units linked by a Campbell Data Logger at Thompson Tower at the 2 m and ~ 38 m levels. Vaisala GPS rawinsondes were launched from a High Mobility Multi-wheeled Vehicle (HMMWV) situated west of Thompson Tower. A 25 kW Quiet Generator powered the HMMWV. The HST was placed north and slightly west of Thompson Tower. This versatile trailer served as the location for Post-test data processing and the Tester's Conference Room.

2.2 Test Execution

A Pre-Test check of equipment and data acquisition was conducted on 19 March 2001.

Test Days 1–3 (2001 March 20–22) began at 0400 Mountain Standard Time (MST), with all participants traveling to the 100 ft Thompson Tower site in a caravan. This strategy served to minimize desert dust around the data acquisition field site. Two data acquisition case studies were scheduled (0500, 0700 MST) and successfully executed. Case I (0500 MST) characterized the pre-dawn desert atmosphere. Case II (0700 MST) coincided with the actual, onsite atmospheric NE. A third case (0800 MST) was added during the Post-Test analysis (See Section 3.2).

On Test Day 1 only, an early morning WSMR Multiple Launch Rocket System (MLRS) mission forced the Case II (0700 MST) RAOB to originate from the WSMR Desert Site location. As an added benefit to the coincident ARL/WSMR missions, RAOB data were also acquired for the hours of 0900 and 1100.

The Thompson Tower data for all cases ran uninterrupted. All RAOBs for Test Days 2 and 3 were launched at the Thompson Tower site.

An Internal Project Review concluded this field test.

2.3 Test Summary

The following summarizes the initial test results, as per the mission statements.

Mission 1. "Day #1 (actual Equinox day) predicted the NE to occur at 0703 MST. The temperature differences radioed to the ground observer reported the single-point NE timing to be 07:03:30 MST. Insolation measurements reported that the sky was completely void of any visible cloud. The NEs for Days #2 and #3 were delayed due (in part) to the occulting effects of cirrus on the eastern horizon." (See Appendixes A and B).

Mission 2. "The Thompson Tower data acquisition was successful for all three Test Days (6 cases). A preliminary review of the insolation, thermodynamic and wind data acquired from both the 2 and 38 m tower levels quantitatively characterized the desert Surface Layer during the night-to-day transition period." (Appendix A).

Mission 3. "Assessing the relationship between the observed angle-of arrival variance as derived from collected imagery, and C_n^2 measured by scintillometer, was halted due to the lack of available parts for the reciprocal scintillometer sensors. A Post-Test effort to attain and install these missing elements was set in motion, with the next targeted deadline of 2001 June Solstice Test." (Vaucher, 2001).

3. Discussion Of Results

3.1 Eulerian and Lagrangian Data Acquisition

The data acquisition for this Experiment/Test took the form of both a Eulerian approach (sampling a fixed volume of atmosphere) and a quasi-Lagrangian approach (following a parcel of air).

The data acquired from sensors mounted on Thompson Tower provided the Eulerian view of the morning ST. The resulting time-series of Pressure (P), Temperature (T), Relative Humidity (RH), Wind Speed (WS), Wind Direction (WD) and Solar Radiation (SR) are displayed in Appendix A. Delta-Temperature (Delta-T) and Environmental Lapse Rate (ELR) time-series were added during the Post-Experiment analysis.

A rawinsonde (RAOB) is a helium-filled, balloon-borne meteorological sensor package that samples a vertical profile of the atmosphere by following the ambient airflow. The atmosphere being traced by the RAOB is not a closed system, therefore, one might refer to this data resource as a quasi-Lagrangian approach. The data acquisition results characterized the vertical atmospheric structure for each case, yielding vertical profiles of P, T, RH, WS and WD. A profile of the ELR was calculated as part of a Post-Test Analysis (Appendix B).

3.2 Defining the Stable, Neutral, Unstable Sub-Cases

For a Post-Test statistical analysis, each Test Day was sub-divided into Stable (Nighttime), Neutral, and Unstable (Daytime) case studies. The definition for each sub-case was a function of both thermodynamics and solar attributes, and are as follows:

Stable (Nighttime): The T difference (T_{38m}–T_{2m}) was positive. SR measurements were equivalent to zero. The duration of data extracted for this case was 1-h.

Neutral: The center point of this case was when the 38–2 m T difference passed through zero. Thirty minutes of data prior to and after this event were included in this case.

Unstable (Daytime): The Delta-T recorded was negative. Sampled SR magnitudes were increasing with time. Since the field experiment data acquisition was often terminated prior to a full hour, a 30-min duration was considered acceptable for this case.

For the 2001 March-Equinox Test, the general data acquisition times for these three sub-cases were approximately 0500–0600 MST (Stable), 06[illegible]730 MST (Neutral), and 0800–0830 MST (Unstable). The following section summarizes the results of the three days of data by their Sub-case. Note that all parameter magnitudes used in the discussion are AVERAGED values for that particular Sub-case.

3.3 2001 March Equinox Test-Synoptic Scale Conditions

The following information was taken from several professional weather Web sites. The resources consisted primarily of weather charts and summaries.

Synoptic conditions for 20–21 March included an upper level ridge over the southwestern states. Storm systems were being diverted far to the north of WSMR. Good surface heating under clear skies set up a three-day warming trend. Moisture over the southwest was sparse. Locally, weather conditions for the 24-h period were sunny and warm in the morning, mostly sunny and warm with light winds later in the day. Sunrise was at 0609 MST.

By Day 2 (21–22 March), the ridge aloft had weakened and there was the developing of a nor'easter over the Carolinas. The northern extent of the ridge was limited by the jet stream stretching from the Pacific-Northwest across the northern tier. The ridge showed periodic flattening, as weak impulse-energy moved through. Locally, 21 March was partly cloudy in the morning, becoming mostly sunny by midday, with warm temperatures, and mostly light to occasionally breezy winds. Sunrise was at 0608 MST.

The final Test day saw a strong west-northwesterly jet stream along the western United States and Canadian border extending over the northern plains. A weak shortwave had moved into California and was projected toward the Four Corners region of NM. Low-level convergence, and the strengthening of mid-level lapse rates increased the morning's partly cloudy skies to cloudiness by the afternoon, with mountain showers threatening the area. Local winds were light to breezy. Sunrise was at 0607 MST. (Forecast for White Sands Missile Range, Intellicast.com, Real-Time Weather Data, 2001).

3.4 Stable Sub-case Results

3.4.1 A Eulerian View (Stable)

By definition, the SR for all three of the Stable atmospheric Sub-cases (2001 March 20–22) was zero (no sun).

The (averaged) 38 m and 2 m T magnitudes agreed with the synoptic analysis by displaying a systematic increase over the three-day period. The largest increase occurred between Day 2 and 3. Maximum-minimum temperatures for both levels over this 1-h case generally spanned 1°, with small variances. By Day 3, the temperature range had increased to approximately 2.5°. Also, the top (.74) and bottom (.97) variances were the largest of the three days. A calculation of the Top-Bottom T covariance and correlation coefficient (R) values showed little correlation between these two levels.

The Stable Sub-case (averaged) Delta-T values for Days 1–3 were +4.1 K ($\sigma = 0.54$), +6.0 K ($\sigma = 0.32$), and +6.7 K ($\sigma = 1.26$), respectively.

The RH displayed a drying trend over the three-day period. Not surprisingly, the greatest humidity was sampled near the surface, where the coldest temperatures were reported. The averaged 2 m RH was approximately double that of the 38 m RH. Variance magnitudes at both the upper and lower levels were small.

The WSs for both upper and lower levels were less than 2 m/s. Averaged WD was primarily northwesterly, implying a drainage flow from the Tularosa Basin's neighboring mountains. On Day 3, the averaged surface wind was less than 0.5 m/s, rendering little significance to the WD average.

3.4.2 A Lagrangian View (Stable)

The Stable 0500 MST Sub-case RAOB launches for Days 1–3 began at 0510, 0506, and 0546 MST, respectively. Ascent rates for the 3 cases were about 3 m/s, with collection periods lasting 67, 25, and 23 min. The P profile showed no significant variation between the three Stable Sub-cases, implying no upper level fronts. Boundary Layer P change with height was consistently –0.1 mb/m. In fact, no significant P variation was seen for any of the cases.

The surface temperature inversions increased each day of the test (30.92, 36.20 and 76.85 K/km). Between Day 1 and Day 2, the height of the inversion increased from 359 to 442 m. However, in Day 3, the inversion strength had more than doubled and did so within about half the height of the first 2 days.

All three days of Stable Sub-case RH profiles displayed the expected negative RH lapse rate (–50, –30, –75%/km, respectively). The depths of the decreasing humidity were 359, 1083, 254 m. Isohume layers below 1 km were abundant (10–23 layers) throughout each of the days.

Airflow gently accelerated with height in both Stable wind profiles acquired (Day 1 and Day 2). The maximum WS was 3.2 and 5 m/s. Not far above this feature, and just below the weak capping inversion, was a distinct jet that had a magnitude of approximately double the lowest level jet. Minor WS maxima framed this larger jet on Day 1. Including the gently increasing surface flow, Day 2 also had minor WS maxima framing the larger jet.

The WD showed no consistent attributes. For Day 1, the 0–1 km WD was backing (counterclockwise) with height. From 1–3 km, there was an oscillation between northwest and north. On Day 2, the entire profile was primarily westerly.

3.5 Neutral Sub-case Results

3.5.1 A Eulerian View (Neutral)

Only Day 1 reported clear skies. Day 1 (averaged) SR was the lowest magnitude of the Test: 155 W/m2. Cloud cover was observed on Days 2 and 3, delaying the NE timing. Averaged SR yielded values of 229 and 204 W/m2. The increased magnitude was interpreted as primarily a function of the neutral Sub-case time period.

The averaged Delta-T was 0.2 K (σ = 1.9 K) for the first two days, and 0.5 (σ = 1.9 K) for the last day. Delta-T ranges for the three days were +3.5 to –2.1 K, +3.8 to –1.8 K, and +4.6 to –1.8 K, respectively

Top (38 m) and bottom (2 m) RH were at their highest on Day 1 (32% and 53%, respectively). The drying trend of Days 2 and 3 placed their RH at less than 35%, with the lowest layer being moister. Winds were from the northern quadrants (drainage) and averaged values less than 2 m/s.

3.5.2 A Lagrangian View (Neutral)

The criterion for the Neutral Case RAOB release time was that it would occur when the 38 m and 2 m Thompson Tower Delta-T registered 0 K. Unfortunately, Day 1 RAOB release time was dictated by the more expensive WSMR MLRS mission, and Day 3 RAOB release time was also delayed. Ultimately, while Day 2 was coincident with the isothermal Tower measurement crossover, the other 0700 MST Cases were only an approximation to a Neutral Atmosphere.

The Neutral Sub-case temperature inversion strengths for these three days (21.6, 14.7 and 15.8 K/km) were significantly less than the Stable Sub-cases. The number of temperature inversions below 3 km for these days were 4, 2 and 1, respectively. Isothermal layers reported were 3, 2, and 1, respectively. Day 2 was distinguished from the others in that if one allows for a +/–0.1 K correction to the temperature data, then the strength of the surface inversion would be reduced to 9.0 K/km. This is most encouraging in that the Day 2 RAOB launch most closely coincided with the ST reported by the Thompson Tower data. Note that an Ideal NE for optical propagation at the original research site was empirically determined to be under near dry adiabatic.

All three Test days sampled the greatest RH near the surface. The height of peak RH magnitudes varied from just above the surface, to 1.5–2 km above ground level (AGL). Also, Isohume layers were still abundant (7–17 layers).

Wind data were available for just the first two days. The strong wind maxima noted in the Stable Sub-cases were still present in the Neutral Sub-case. Two weaker flows were present below the stronger air stream on Day 1. These held the same directions as the

Stable Sub-case. Day 2's weaker flow near the surface was primarily southwesterly, with a distinct westerly flow dominating the 1–5 km (boundary and free atmosphere) layers.

3.6 Unstable Sub-case Results

3.6.1 A Eulerian View (Unstable)

The Unstable Sub-cases for Day 2 and Day 3 occurred at nearly the same time. Therefore, it is no surprise that the SR values were similar (431 and 463 W/m^2). Data availability placed the Unstable Sub-case of Day 1 data about 30 min earlier. Consequently, the SR is only 304 W/m^2. Interestingly, the averaged Delta-T for Day 1 and Day 2 are both –1.6 K (Day 3 is –1.9 K).

The RH for the earlier Unstable Sub-case (Day 1) was observed to have the greatest magnitude at the lower level (a Neutral and Stable characteristic). Day 2 and Day 3's RH were notably drier. Top and Bottom measurements for both days had the same values, factoring in the relatively small standard deviation (< 1%). Without the adjustment, Day 2 bottom RH was slightly greater than the top RH, and Day 3 bottom RH was slightly less than the top RH.

Calm to light-and-variable winds were observed during all 3 days.

3.6.2 A Lagrangian View (Unstable)

Day 1 was the only day with Unstable Sub-case RAOB data. As expected, no surface temperature inversion was present. Instead, the Surface ELR was –10.7 K/km. The lowest level temperature inversion was reported as +1.4 K between 243 and 498 m AGL. The ELR for this inversion was +5.5 K/km. Two isothermal layers preceded the only other Boundary Layer temperature inversion (1916–2053 m). An isothermal layer, 54 m thick, lay above this upper level inversion, making the full layer 1916–2107 m. This upper level feature (ELR = 2 K/km) was presumed to be the capping inversion.

The increasing RH, with height peaked at 243 m AGL, the base of the decaying nocturnal inversion layer. From 243 to 2053 m, the RH displayed a drying trend. Only 6 Isohume layers were sampled within the first km.

The wind profile displayed the same low-level jet framed by two weaker flow maxima patterns seen in both the Stable and Neutral Sub-cases. The magnitude was approximately half that of the Stable Sub-case's low-level jet. The WD for this jet was northeast. The smaller currents were northwest.

4. Summary

In July 2002, the U.S. Army Chief of Staff Shinseki stated that his vision for the current and future U.S. Army was "to see first, act first, kill first.... To see first, we must have persistent and pervasive intelligence-gathering capabilities." (Burlas, 2002). One of the greatest hurdles to seeing first is the atmosphere. Depending on the atmospheric conditions, the atmosphere can be a friend or a foe. The Boundary Layer Exploitation-Atmospheric Stability Transition Research defines the naturally occurring friendly and non-friendly atmospheric conditions, and is one link in the non-trivial effort of discriminating between them as they pertain to military applications. In fact, by differentiating between the friendly and non-friendly atmospheric conditions, ARL expands U.S. Army Chief of Staff Shinseki's vision from "to see first," to, "to see better." Under friendly atmospheric conditions, the identification of targets can theoretically be done quicker, making the last two actions of Shinseki's vision for the U.S. Army more efficient and more effective.

The ST study has further military applications in the powerful laser weapons arena, as well as the area of chemical and biological weapons hazards plaguing urban warfare. By knowing the timing and characteristics of the STs, the atmospheric impact, i.e. whether the weapon's effectiveness will be enhanced or diminished, can be better evaluated.

Likewise, establishing the initial conditions of the convective Boundary Layer growth phase (the ST) is of primary interest to both the civilian and military Convective Boundary Layer and other Atmospheric Dispersion/Diffusion Modelers. Results from these time-evolving models often reflect the accuracy of their initial starting points. For the military, knowing when a smoke screen will disperse, for example, could prove to be a significant strategic advantage on a battlefield. Thus, the exploitation of the ST pattern ties to several military and civilian interests and applications (Angevine et al., 2001).

This document is the first of three technical reports stemming from a study with the governing purpose of characterizing, modeling and exploiting the lower portion of the Atmospheric Boundary Layer, the Surface Layer. The specific Surface Layer activity being investigated was the ST. The March Equinox time period was selected because of its previous statistical association with the minimal amount of time observed between local sunrise and a NE, under Ideal desert atmospheric conditions.

4.1 Neutral Event Forecast Model Validation

The question of whether the NE Forecast Algorithm developed in the mid-1990s at HELSTF, NM was site-specific was partially answered during the only Ideal Case

observed (Day 1). Here, the forecasted and observed times were coincident. The occulting of the sun by clouds on the eastern horizon prohibited any further Ideal Condition NE Forecast Algorithm validation.

4.2 Characterizing the Morning Stability Transition

Characterizing the atmosphere undergoing a ST was another objective of this study. The strategy employed for this effort was to contrast three sub-cases: Nighttime (Stable), Neutral, and Daytime (Unstable) conditions. Two perspectives on these 3 sub-cases were examined: a Eulerian and a quasi-Lagrangian approach.

Measurements for the Eulerian approach came from tower data sampled at two levels (38 m and 2 m). The quasi-Lagrangian perspective was provided by rawinsonde data initiated at or near Thompson Tower for each of the stability sub-cases.

4.2.1 Stable Sub-cases

The 60 min of Eulerian data characterized the Stable sub-cases as having no SR (by definition), a 38 m minus 2 m Delta-T of +4 to +7 K, greatest moisture near the surface with very small variances, winds that were light and from the directions typical of a drainage flow off the neighboring mountains.

The Lagrangian Stable Sub-case data reported strong surface inversions ranging between 30 and 77 K/km. The RH concurred, with the greatest RH near the surface, in addition to several layers of Isohume conditions. The vertical wind profile showed one major low-level jet framed by weaker flow maxima. Drainage flow was implied.

4.2.2 Neutral Sub-cases

The fixed-point perspective centered the 60 min of Sub-case data on the actual observed transition. Averaged SR for the Ideal case was 155 W/m^2. The Non-ideal cases reported larger values. Not surprisingly, the averaged Delta-T magnitudes hovered around the positive side of 0 K for all three sample sets. The ranges for the Delta-T began around +4 K, and decreased to approximately –2 K. The greatest RH was found near the surface. Winds were light and tending to be from the northern sectors (implying drainage).

The Lagrangian perspective presented the surface temperature inversions between +14 and +22 K/km. Other inversions and isothermal layers were present within the Boundary Layer vertical profiles. The RH continued to show the moister layer to be near the surface, with several Isohume layers within the Boundary Layer. The gross features of the wind profile were very similar to the Stable Sub-case. The characteristic low-level jet, however, was at a higher level than the Stable Sub-case.

4.2.3 Unstable Sub-cases

The SR was approximately double that of the Neutral Sub-cases. The Delta-T magnitudes were around –2 K. The RH presented mixed results. One case maintained the greatest humidity near the surface (clear skies), while the other two showed a more homogenous structure. Winds were calm to light-and-variable for all three days.

A single data source provided the Lagrangian perspective. These data sampled a surface lapse rate of –11 K/km, an elevated inversion (ELR = +6 K/km) and a capping inversion of about +2 K/km. The RH profile peaked at the base of the first inversion and had the fewest reported Isohume layers within the Boundary Layer of the Sub-cases. The Unstable wind profile propagated the pattern of the Stable and Neutral Sub-cases. That is, the data reported a strong, low-level jet framed by two weaker flow maxima.

5. Conclusions

Conclusions are best drawn from a completed data set. This document presents only one-third of the study's results. While the authors were very much encouraged by the single point Ideal Conditions validation of the NE Forecast Model, the resource was only a single point and must be kept in perspective. The characterizing of the March conditions was helpful in that a foundation or standard for contrast has been etched. Once the next two pieces of this atmospheric puzzle are completed, a gleaning of conclusions will be pursued.

Acronyms

AOT	Atmospheric Optical Turbulence
ASL	Atmospheric Surface Layer
ARL	U.S. Army Research Laboratory
AGL	Above Ground Level
Cn2	Index of Refraction Structure Function
Delta-T	Temperature Difference [T38m – T2m]
ELR	Environmental Lapse Rate
GPS	Global Positioning System
HEL	High Energy Laser
HELSTF	High Energy Laser Systems Test Facility
HMMWV	High Mobility Multi-wheeled Vehicle
HST	High Speed Trailer
MIT	Meteorological-sensors Integration Team
MLRS	Multiple Launch Rocket System
MST	Mountain Standard Time
NE	Neutral Event
P	Pressure
RAOB	Rawinsonde Observation System
RH	Relative Humidity
SLST	Surface Layer Stability Transition
SR	Solar Radiation
SRNE	Sunrise Neutral Event
ST	Stability Transition
T	Temperature

WS	Wind Speed
WSMR	White Sands Missile Range
WD	Wind Direction

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Appendix A. Thompson Tower Data

This appendix is part of ARL-TR-2798, Surface Layer Stability Transition Research Minimum Time Delay from Sunrise: 2001 March Case Study, U.S. Army Research Laboratory, White Sands Missile Range, NM 88002-5501.

A Eulerian (fixed point) perspective on the atmospheric conditions during the Nighttime (Stable) to Daytime (Unstable) transition was quantitatively recorded by the Thompson Tower time-series data. Sampling was executed at 2 m and 38 m above ground level (AGL). For convenience, we have designated data representing the lower layer with a brown box and the upper layer with a blue open circle. Efficiency has dictated that all three Sub-cases (Stable, Neutral, Unstable) be presented in a single time-series plot. Approximate times for each Sub-case were:

Stable	0500–0600 MST
Neutral	0630–0730 MST
Unstable	0800–0830 MST

The Pre-Test data acquired on 2001 March 19 were included with the scheduled Test (20–22 March) for completeness. The following are the four sections of Appendix A:

- Figures A1–A8: 2001 March 19
- Figures A9–A16: 2001 March 20
- Figures A17–A24: 2001 March 21
- Figures A25–A32: 2001 March 22

Figures A1–A8: 2001 March 19-Thompson Tower Data

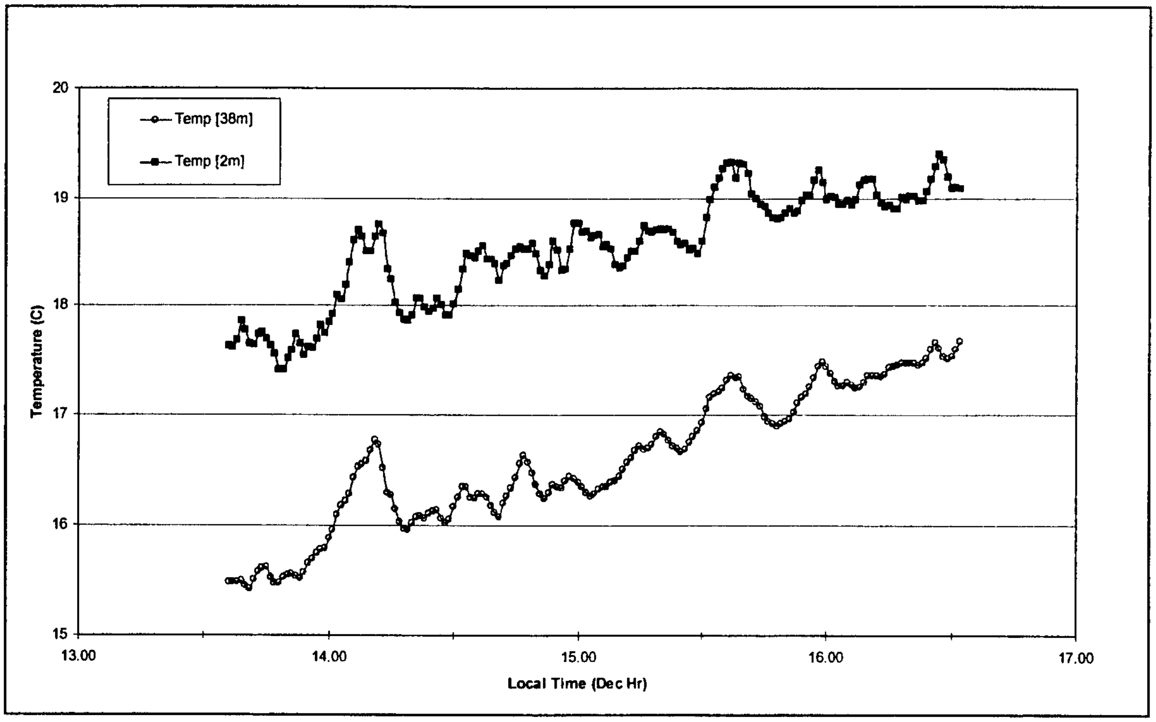

Figure A1. Thompson Tower-2001 March 19: Temperature.

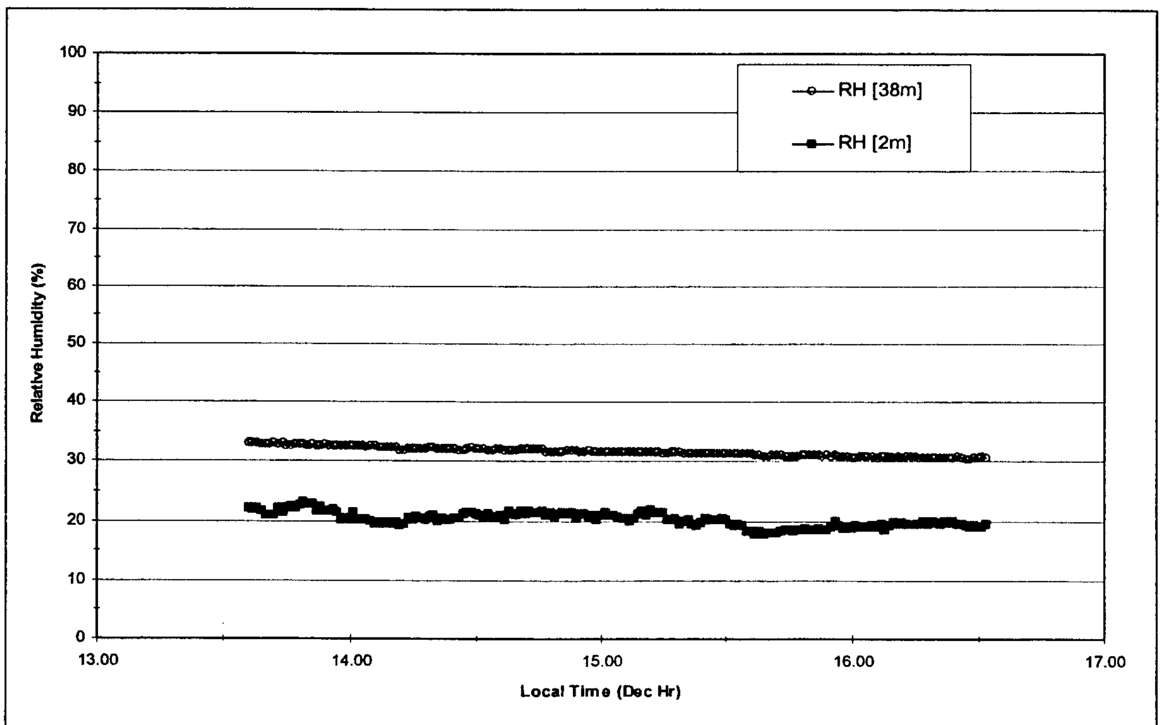

Figure A2. Thompson Tower-2001 March 19: Relative Humidity.

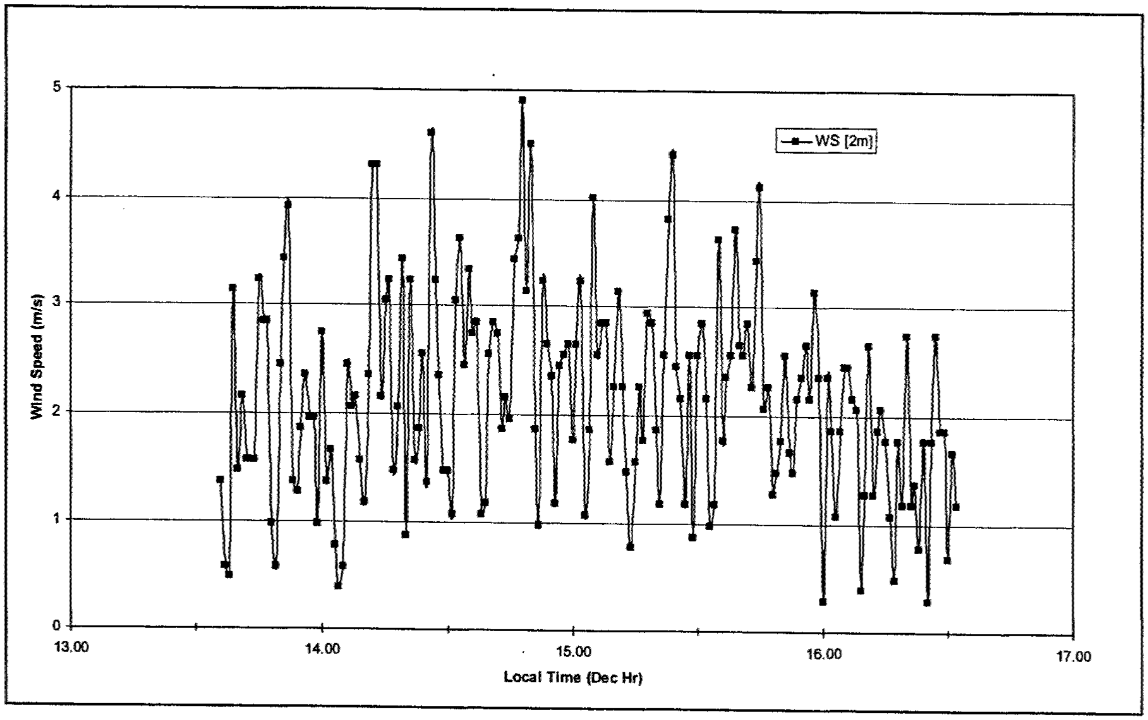

Figure A3. Thompson Tower-2001 March 19: Wind Speed.

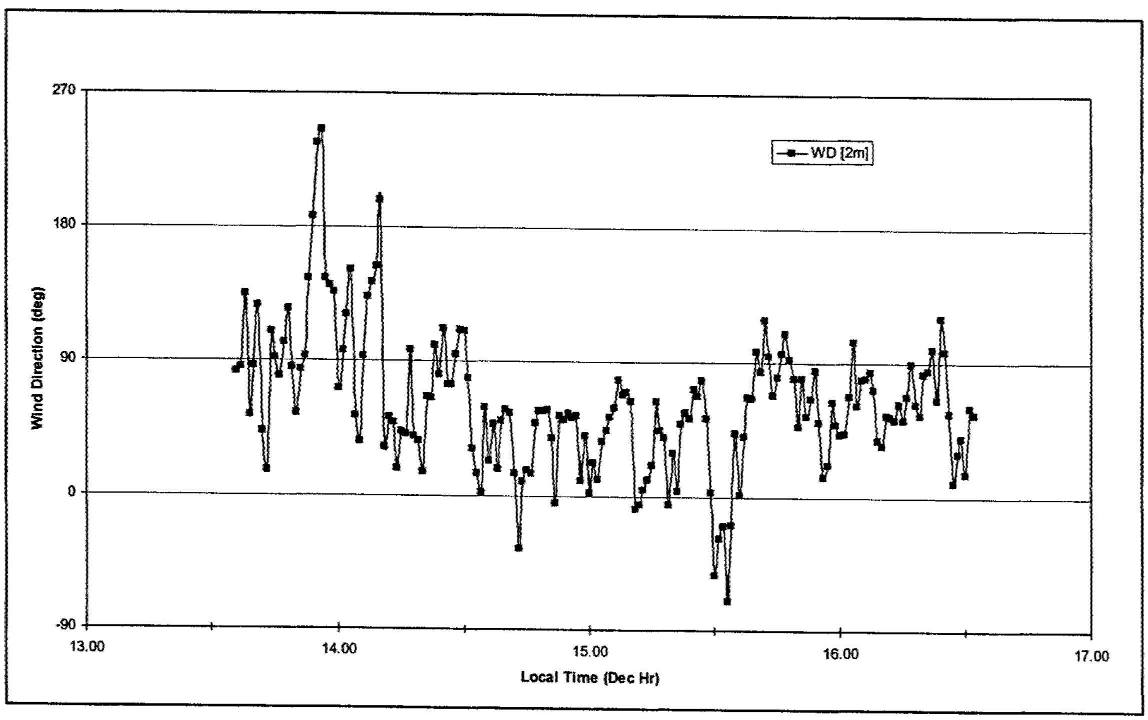

Figure A4. Thompson Tower-2001 March 19: Wind Direction.

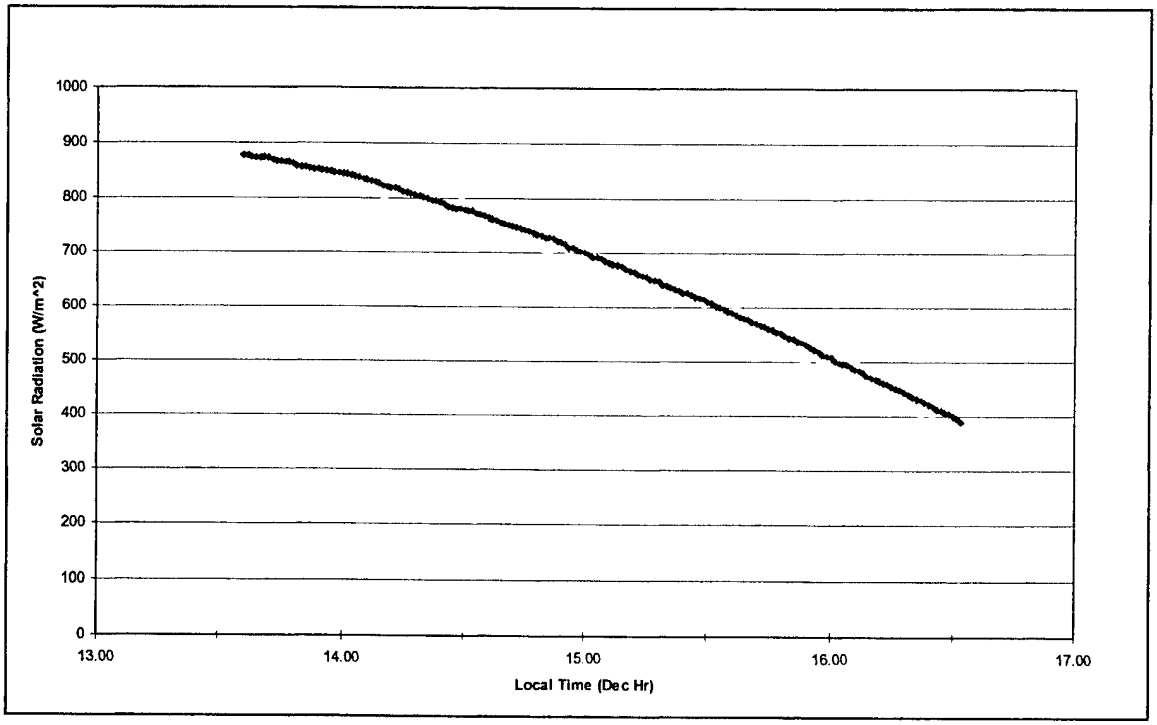

Figure A5. Thompson Tower-2001 March 19: Solar Radiation.

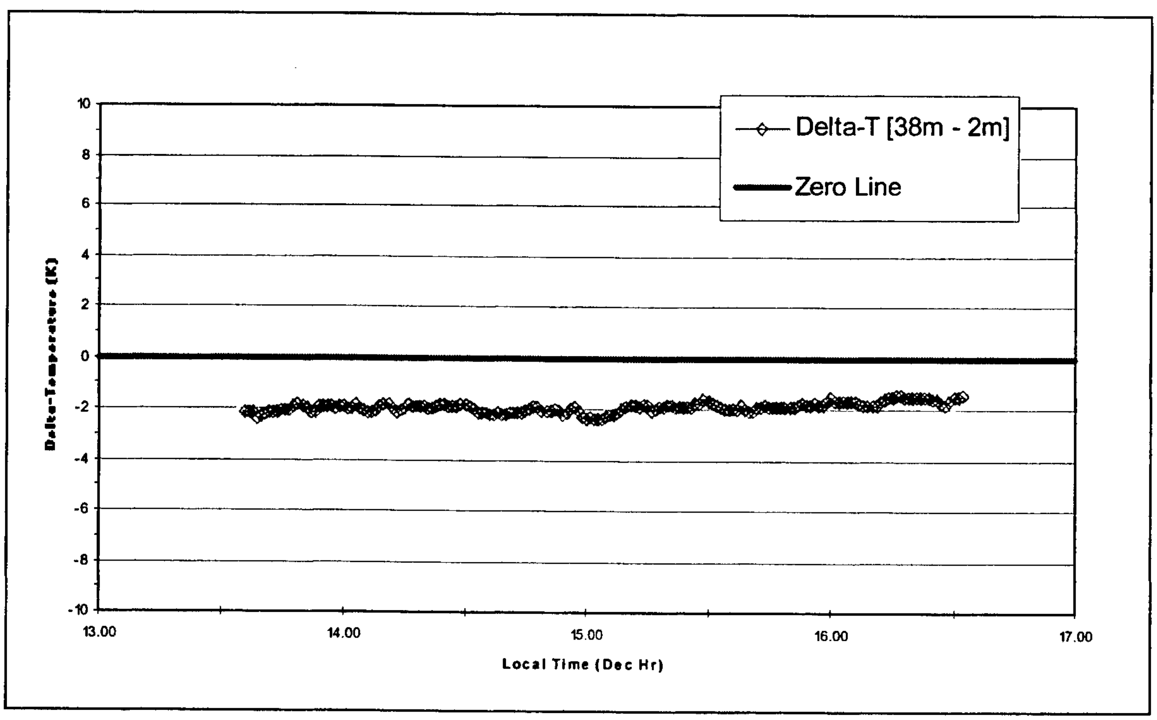

Figure A6. Thompson Tower-2001 March 19: Delta-T.

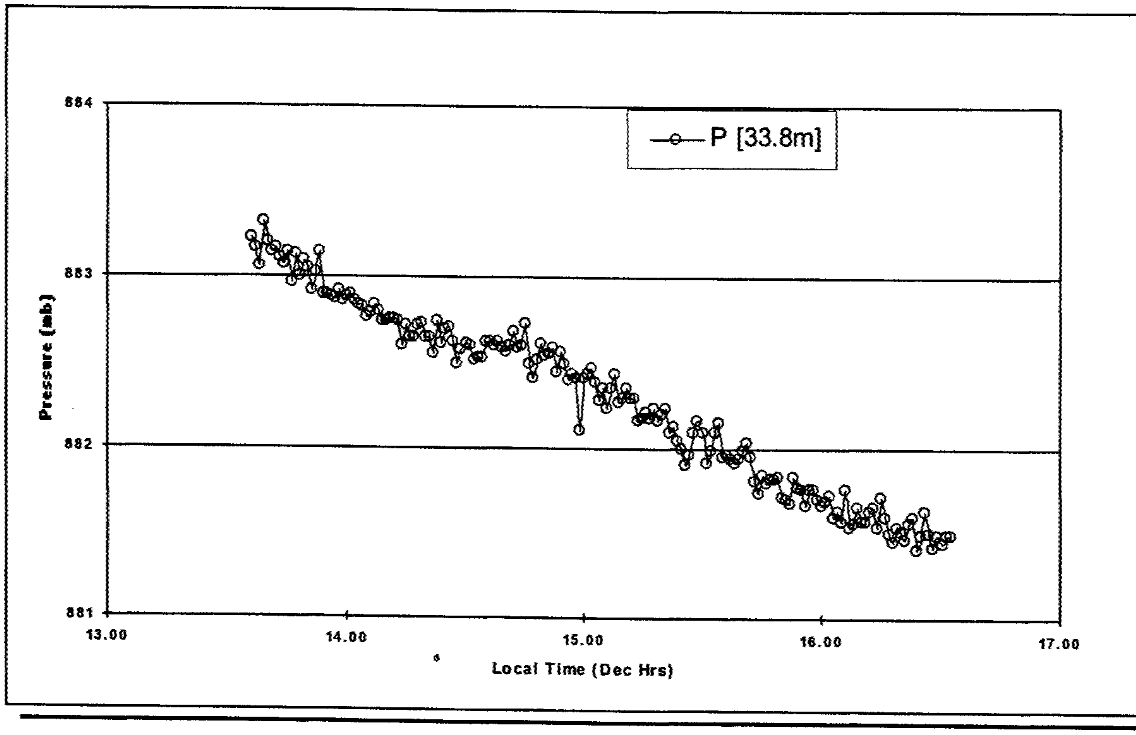

Figure A7. Thompson Tower-2001 March 19: Pressure.

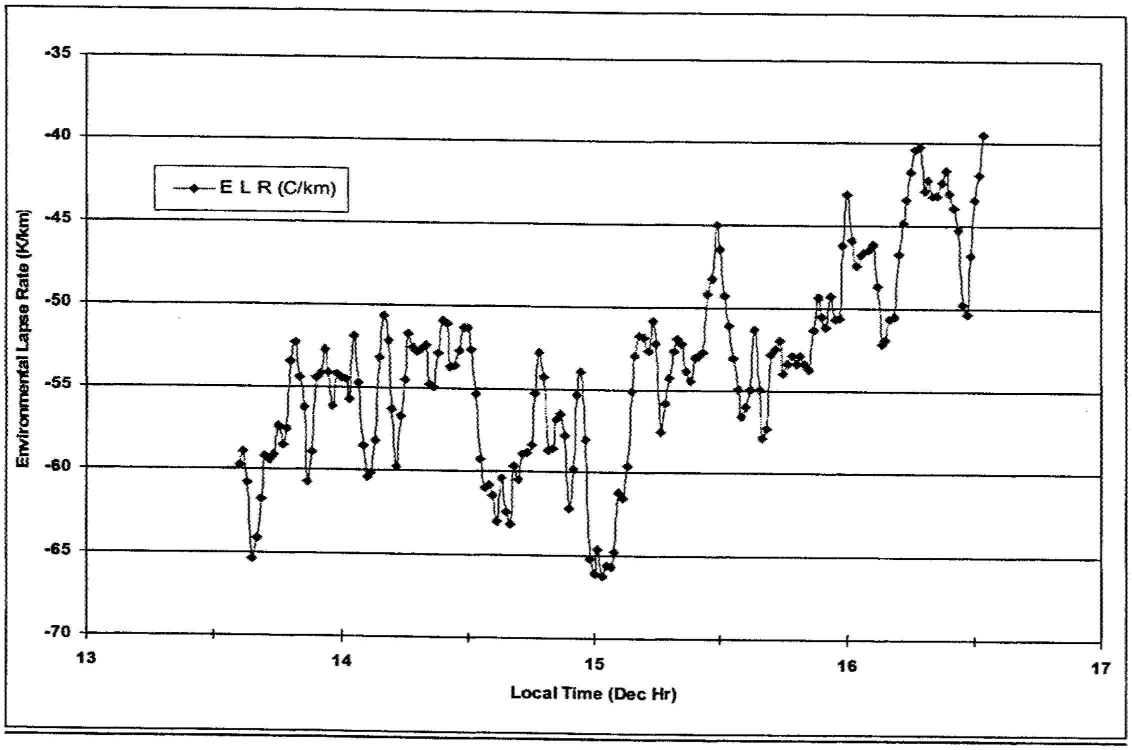

Figure A8. Thompson Tower-2001 March 19: ELR.

Figures A9–A16: 2001 March 20-Thompson Tower Data

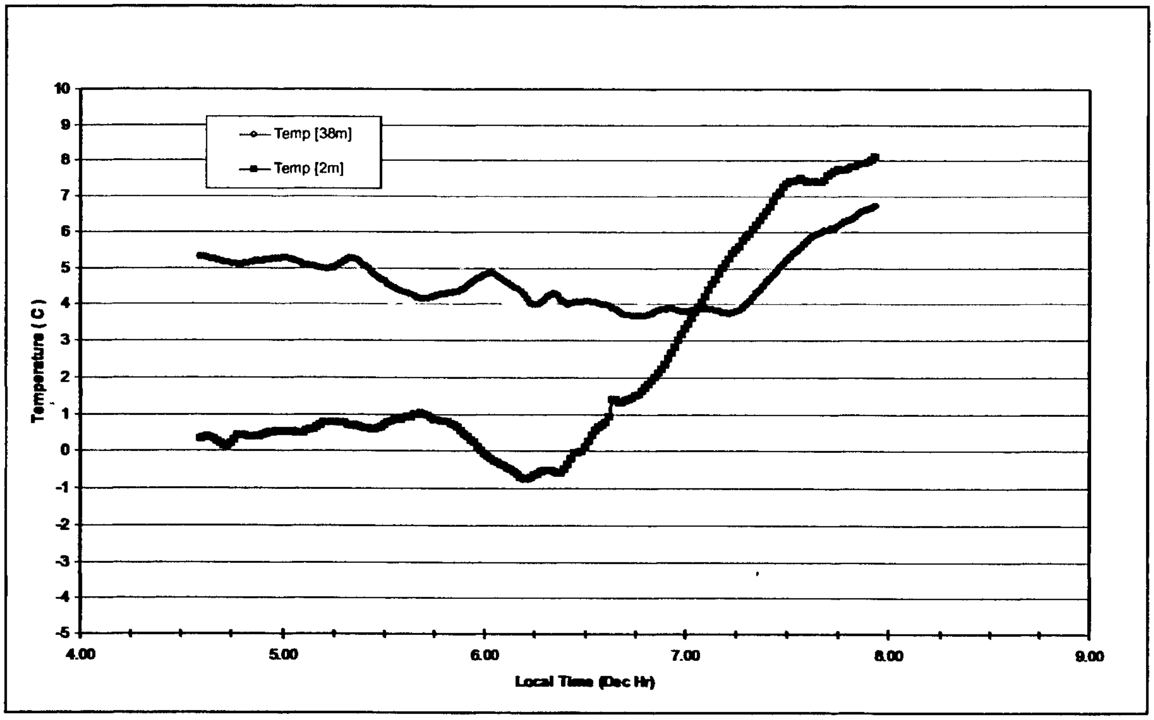

Figure A9. Thompson Tower-2001 March 20: Temperature.

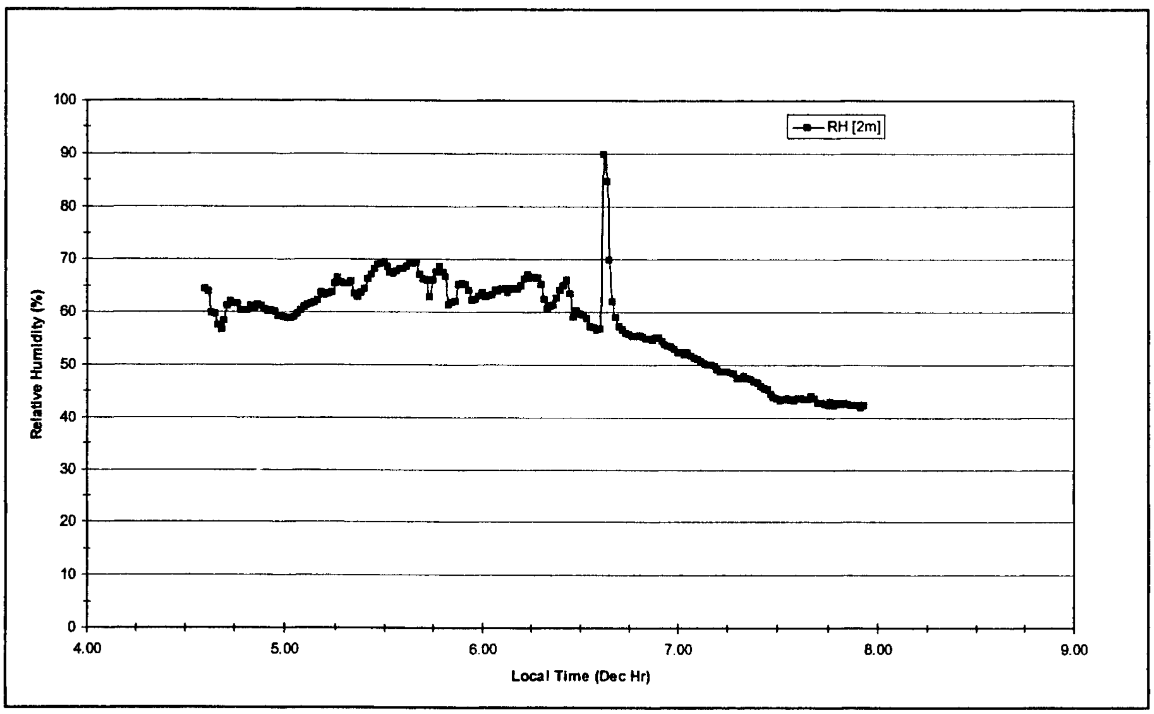

Figure A10. Thompson Tower-2001 March 20: Relative Humidity.

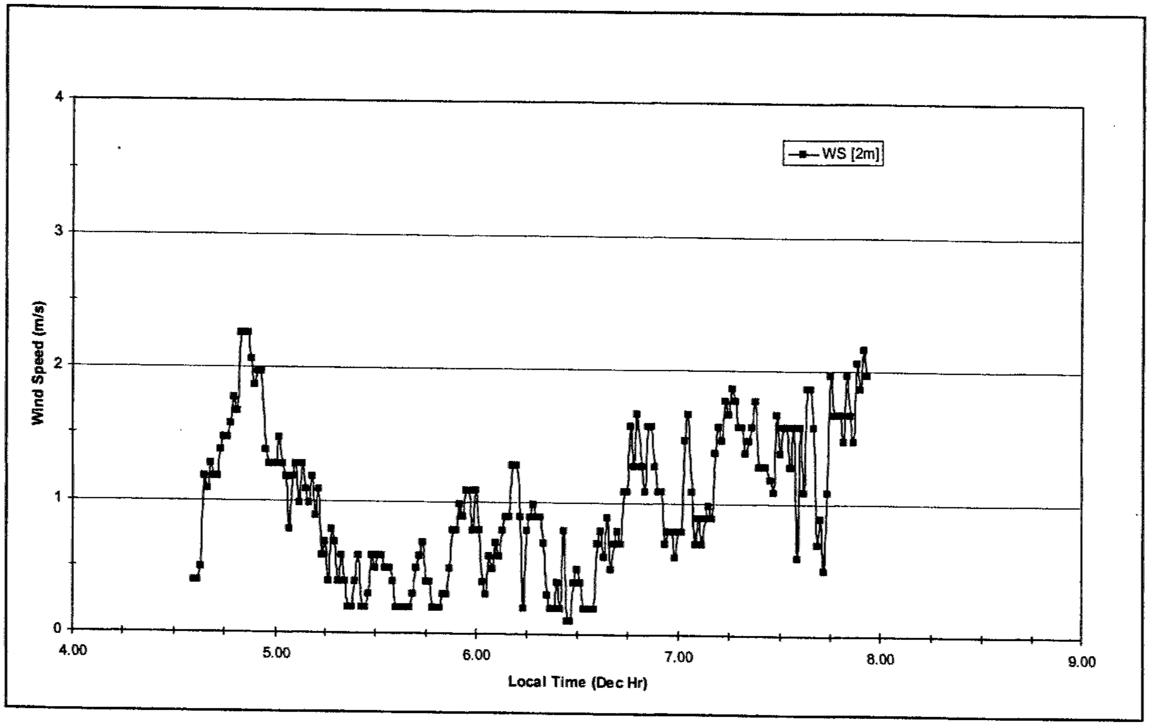

Figure A11. Thompson Tower-2001 March 20: Wind Speed.

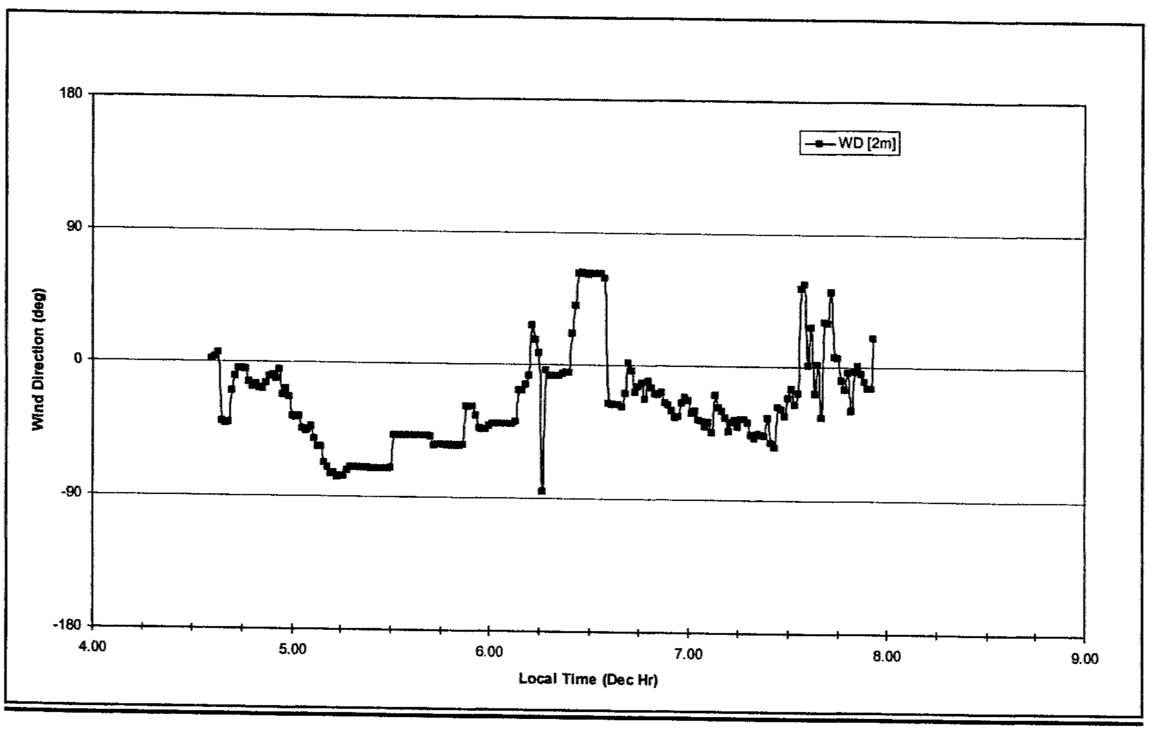

Figure A12. Thompson Tower-2001 March 20: Wind Direction.

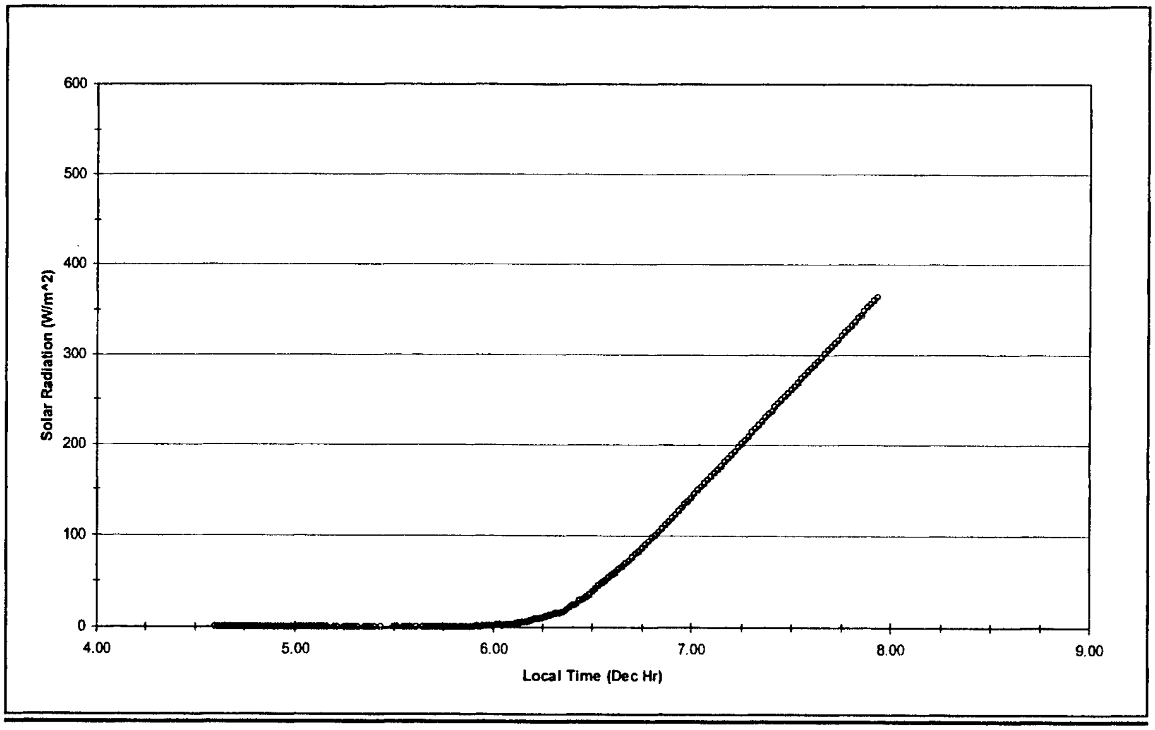

Figure A13. Thompson Tower-2001 March 20: Solar Radiation.

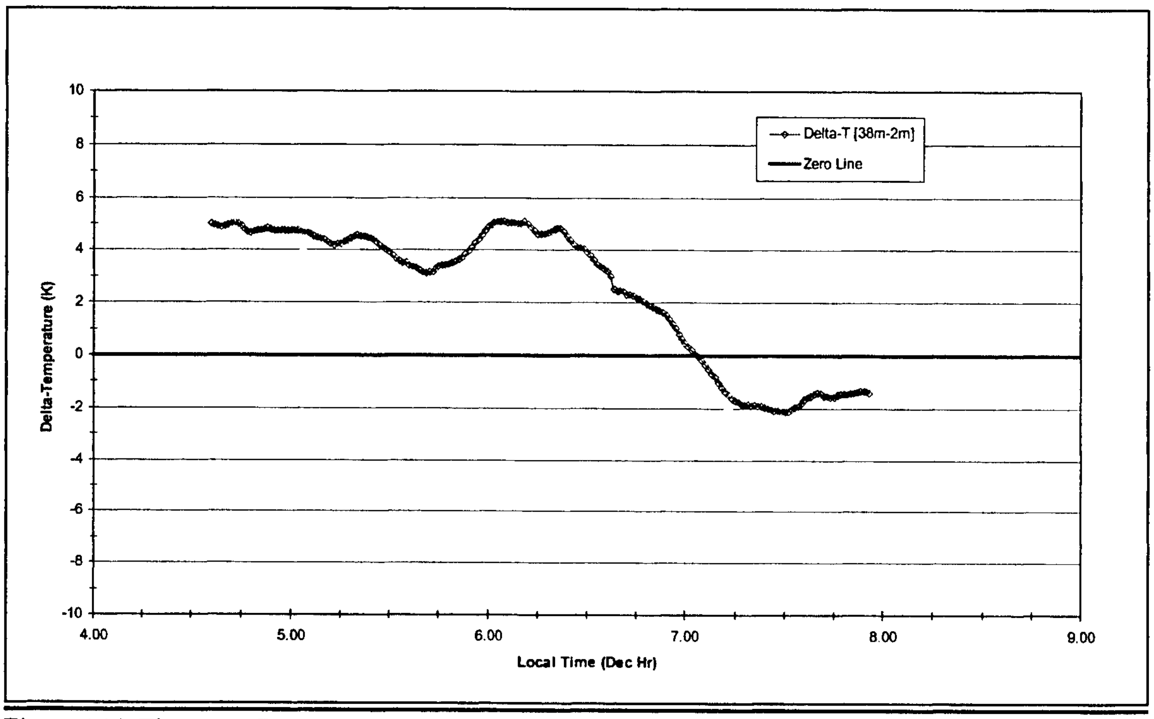

Figure A14. Thompson Tower-2001 March 20: Delta-T.

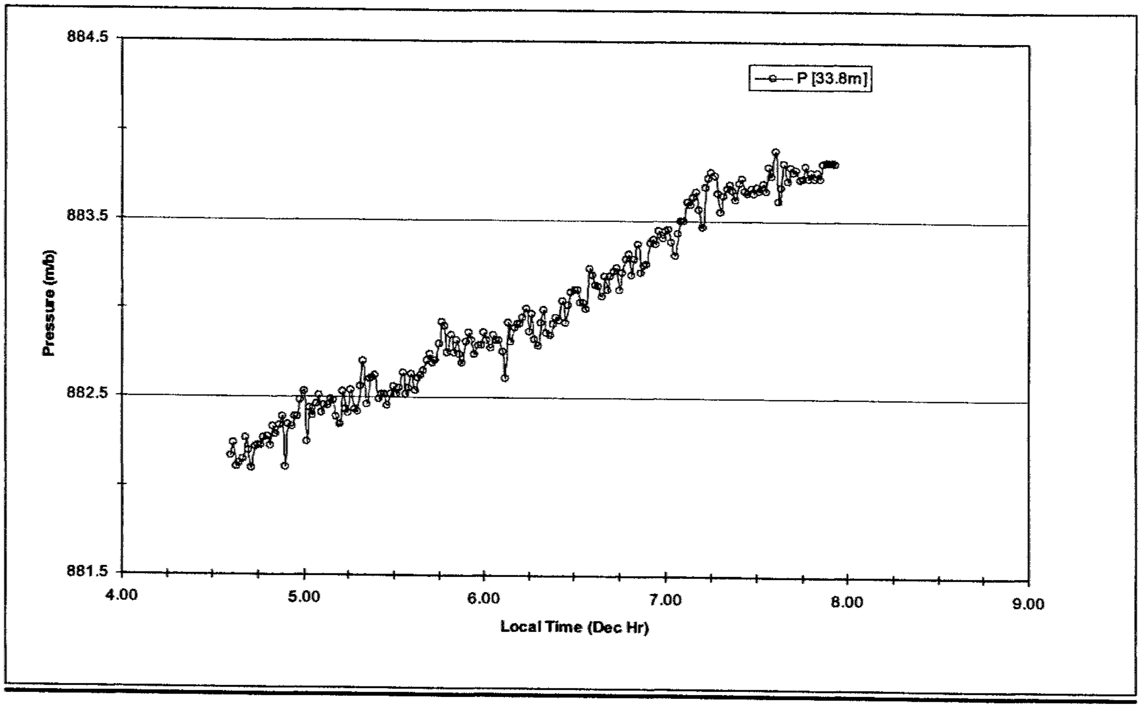

Figure A15. Thompson Tower-2001 March 20: Pressure.

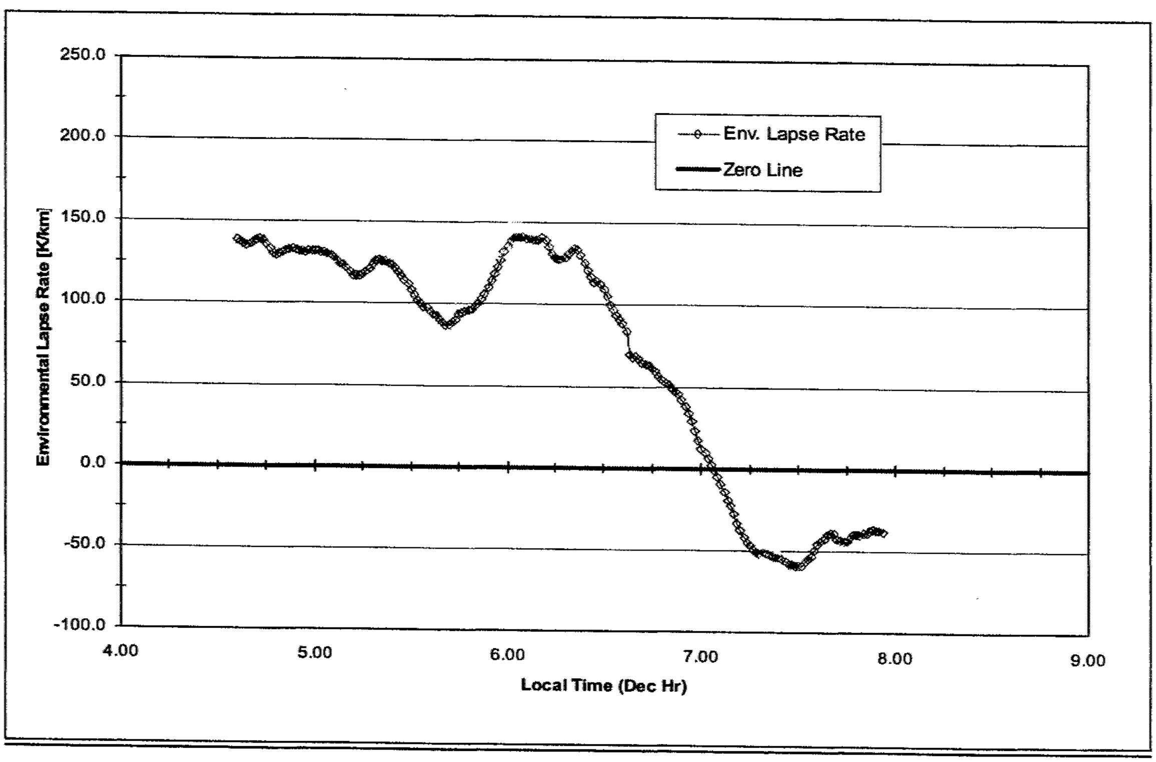

Figure A16. Thompson Tower-2001 March 20: ELR.

Figures A17–A24: 2001 March 21-Thompson Tower Data

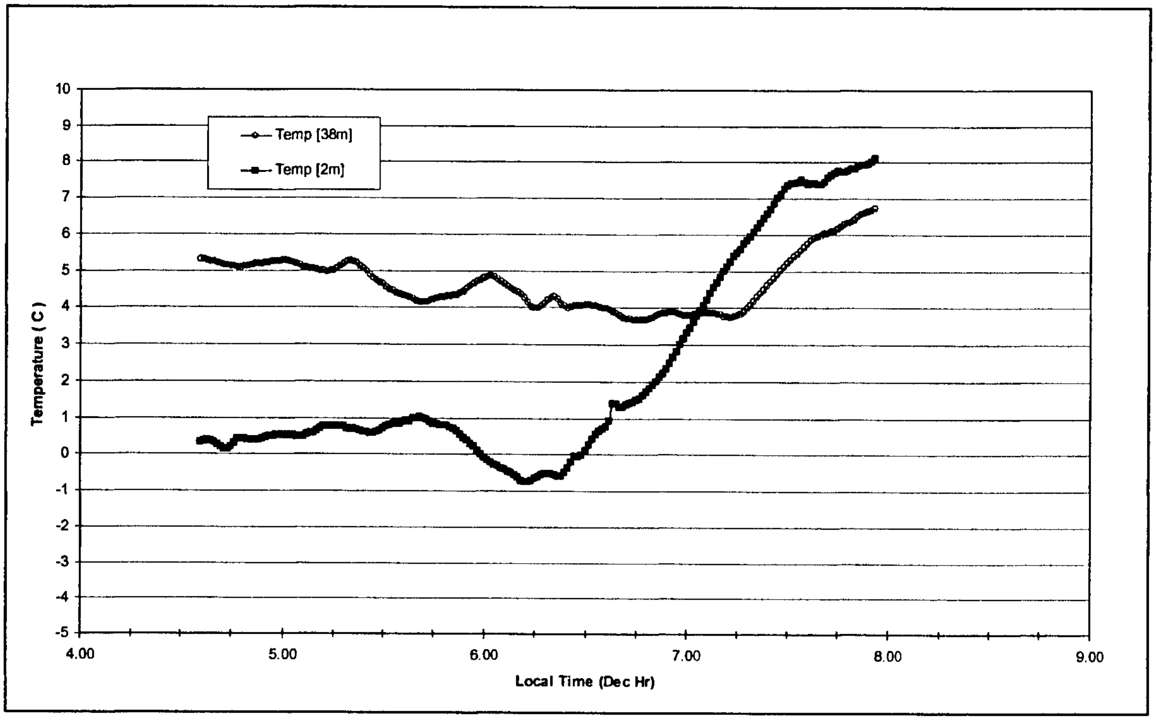

Figure A17. Thompson Tower-2001 March 21: Temperature.

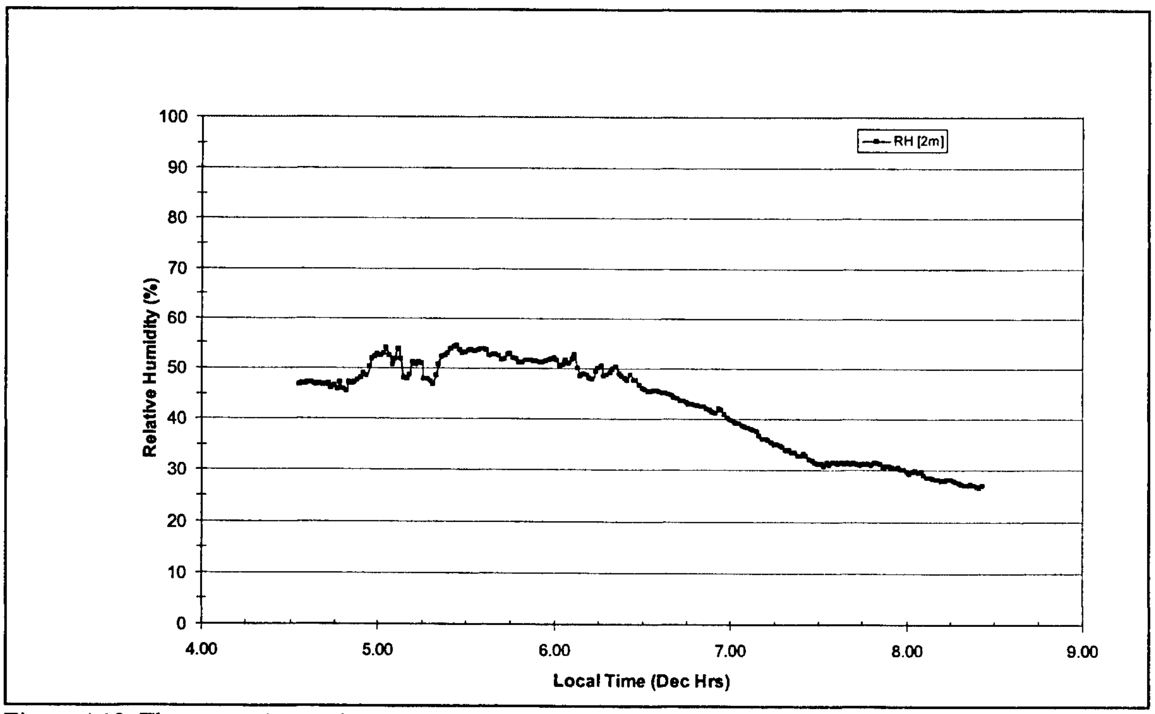

Figure A18. Thompson Tower-2001 March 21: Relative Humidity.

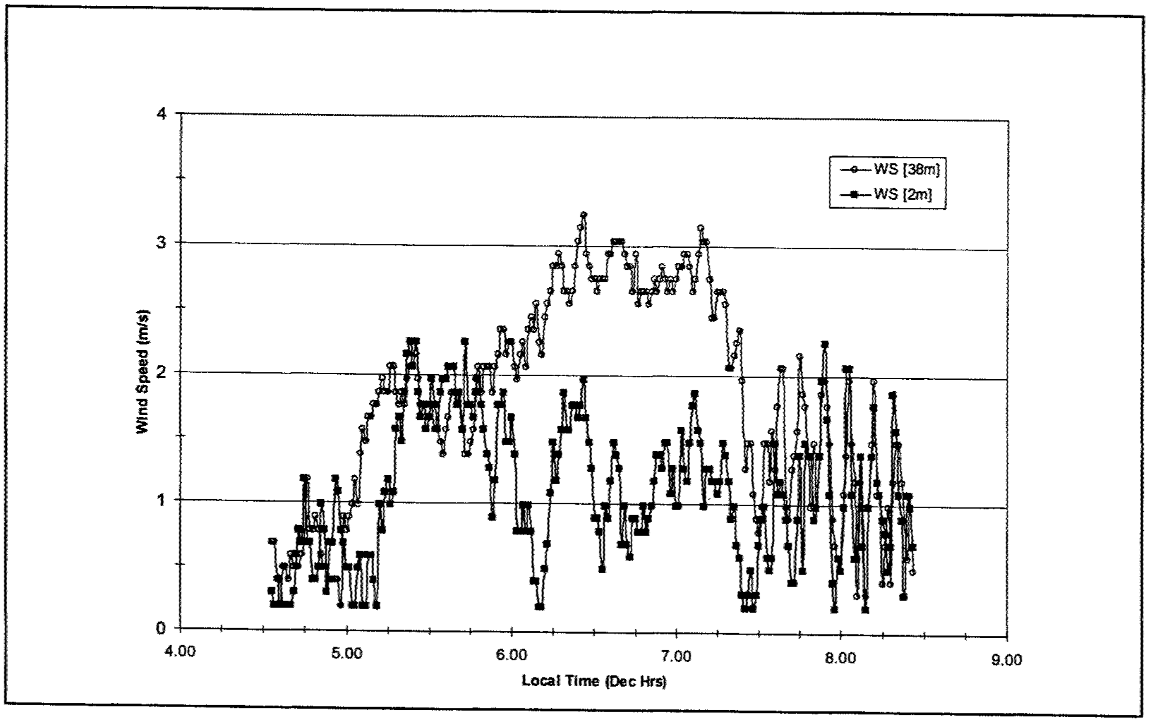

Figure A19. Thompson Tower-2001 March 21: Wind Speed.

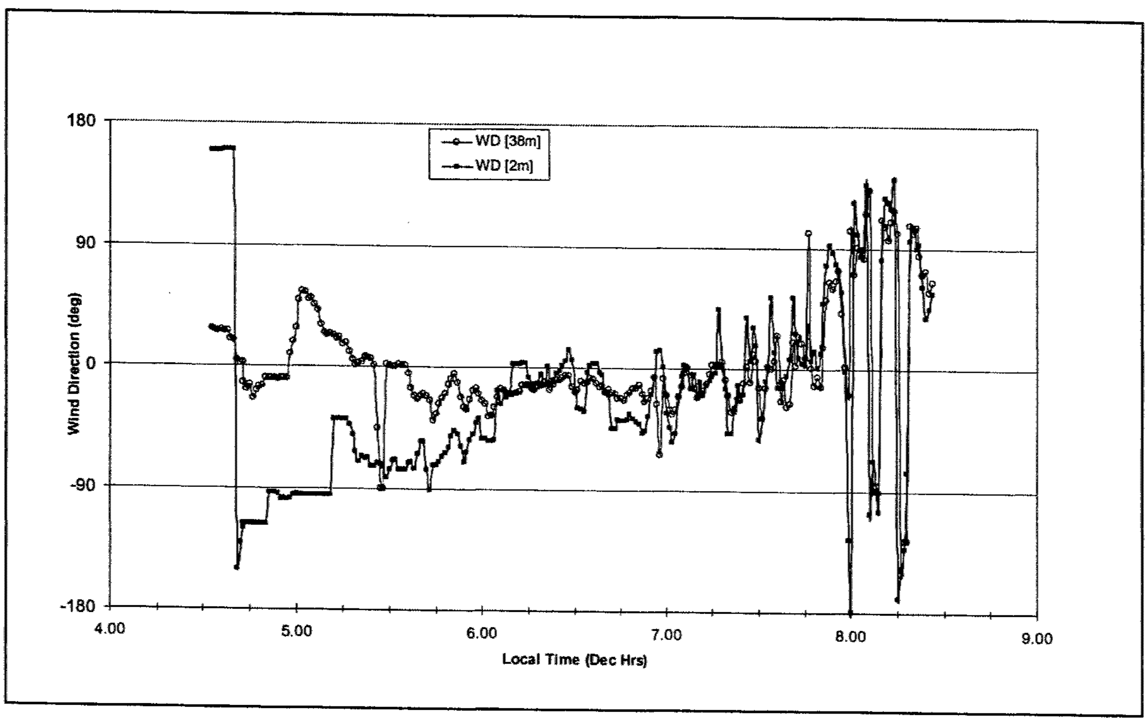

Figure A20. Thompson Tower-2001 March 21: Wind Direction.

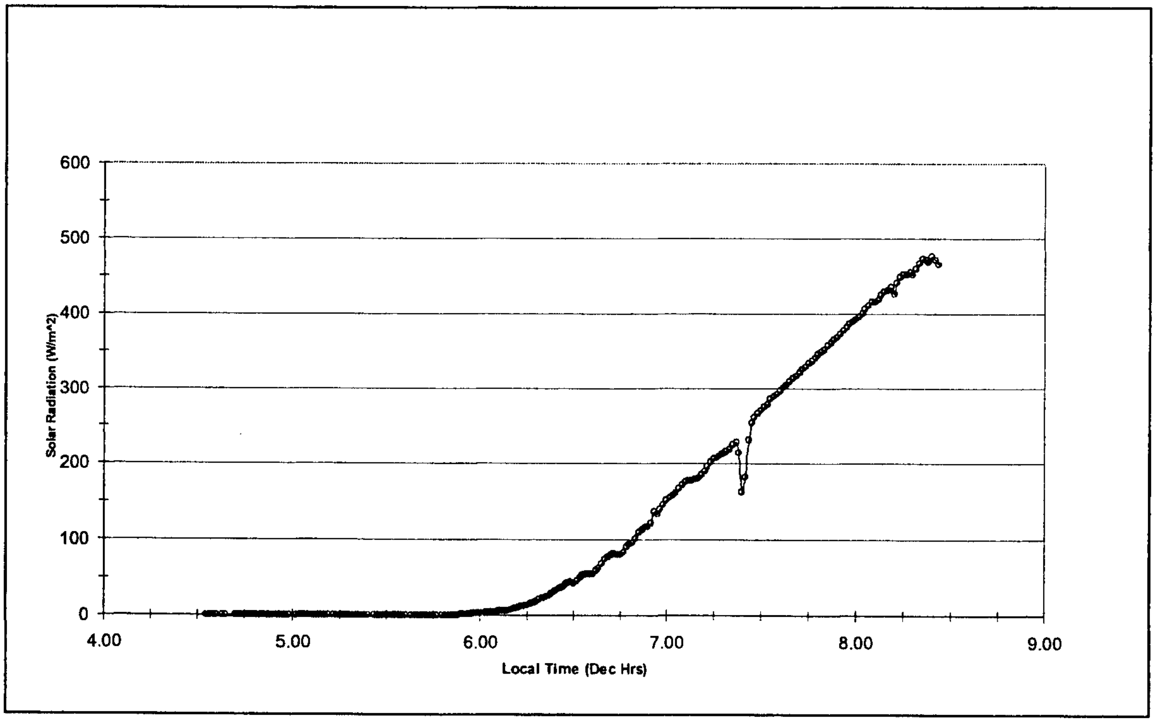

Figure A21. Thompson Tower-2001 March 21: Solar Radiation.

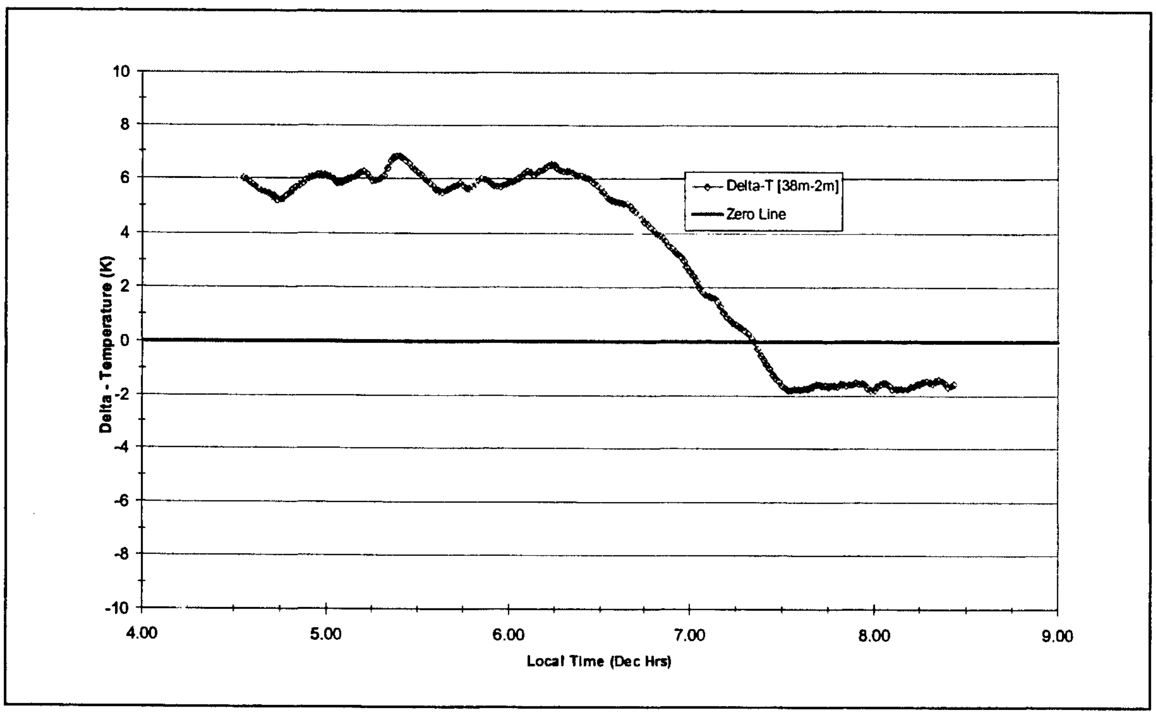

Figure A22. Thompson Tower-2001 March 21: Delta-T.

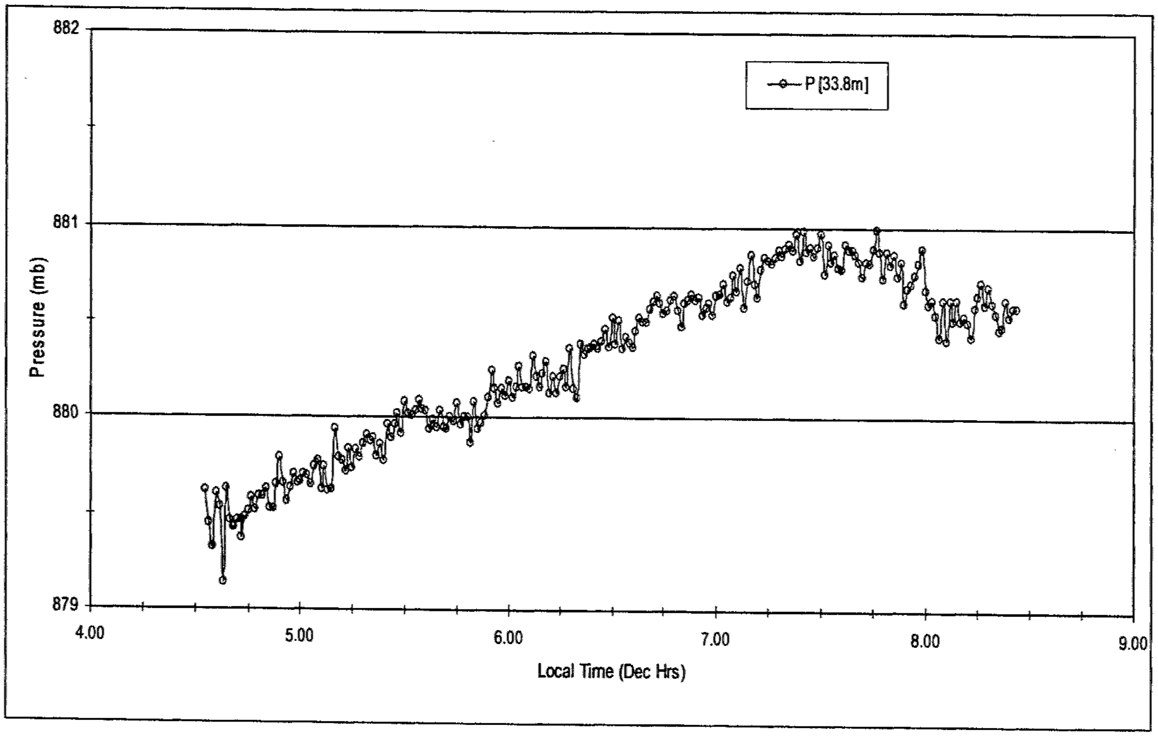

Figure A23. Thompson Tower-2001 March 21: Pressure.

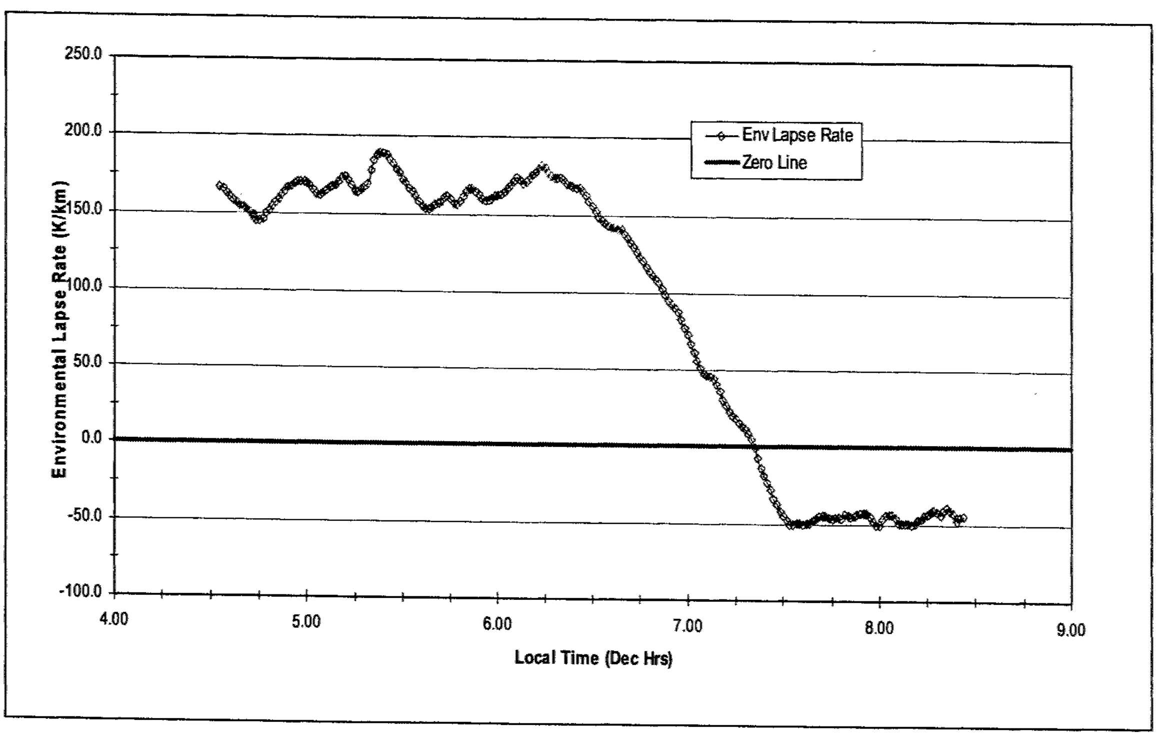

Figure A24. Thompson Tower-2001 March 21: ELR.

Figures A25–A32: 2001 March 22-Thompson Tower Data

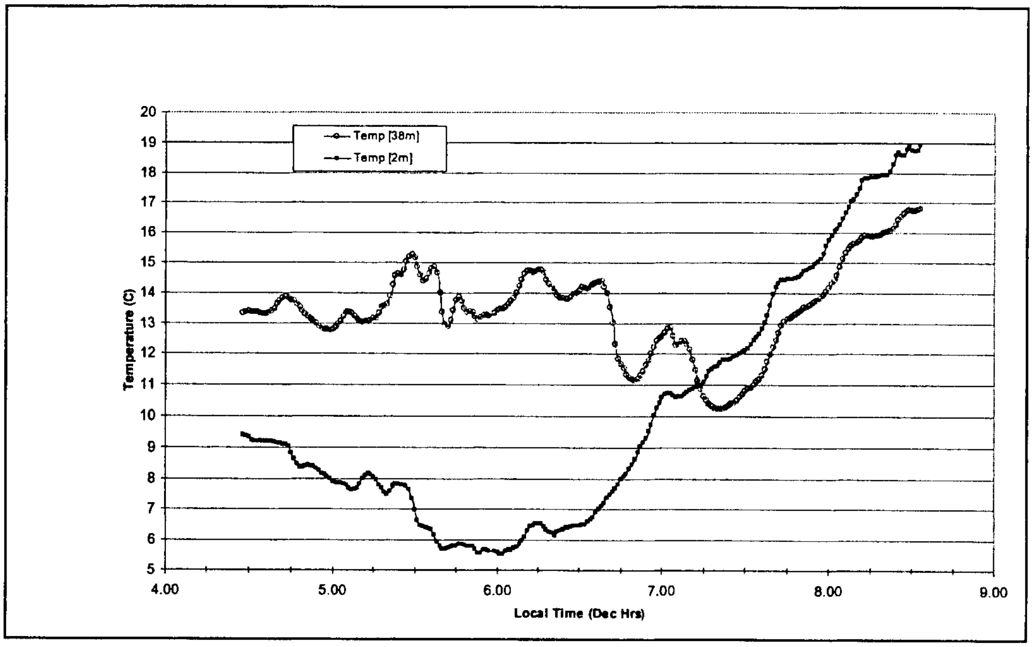

Figure A25. Thompson Tower-2001 March 22: Temperature.

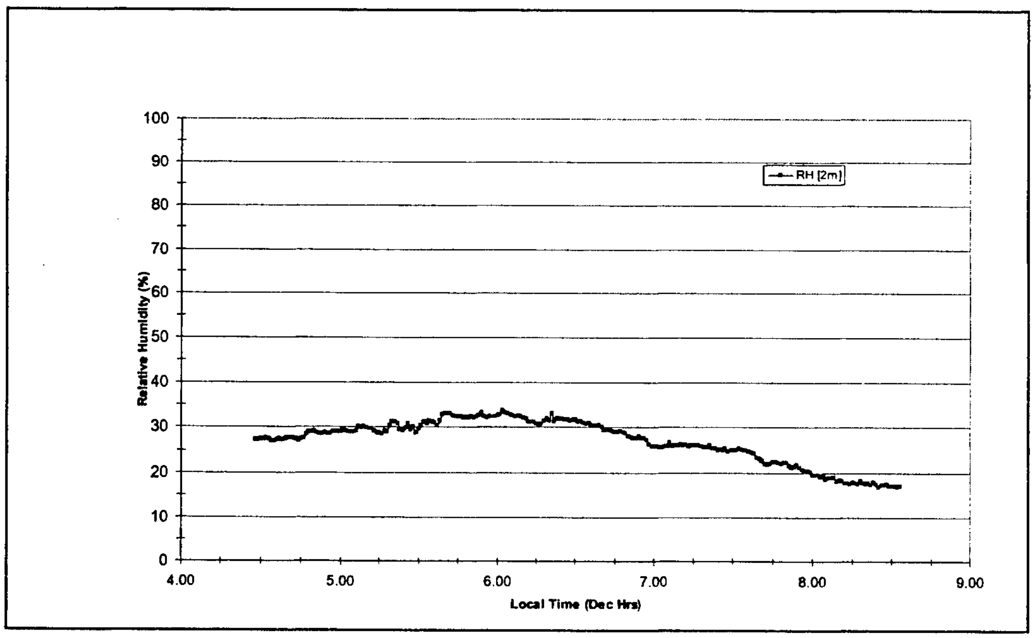

Figure A26. Thompson Tower-2001 March 22: Relative Humidity.

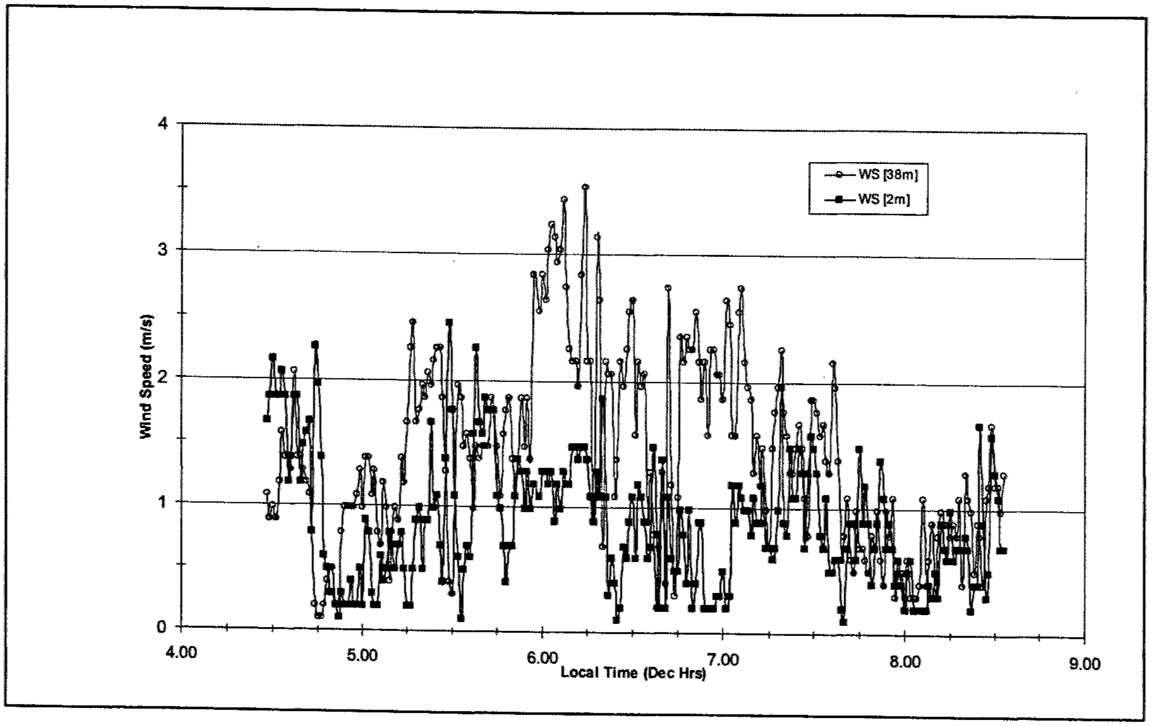

Figure A27. Thompson Tower-2001 March 22: Wind Speed.

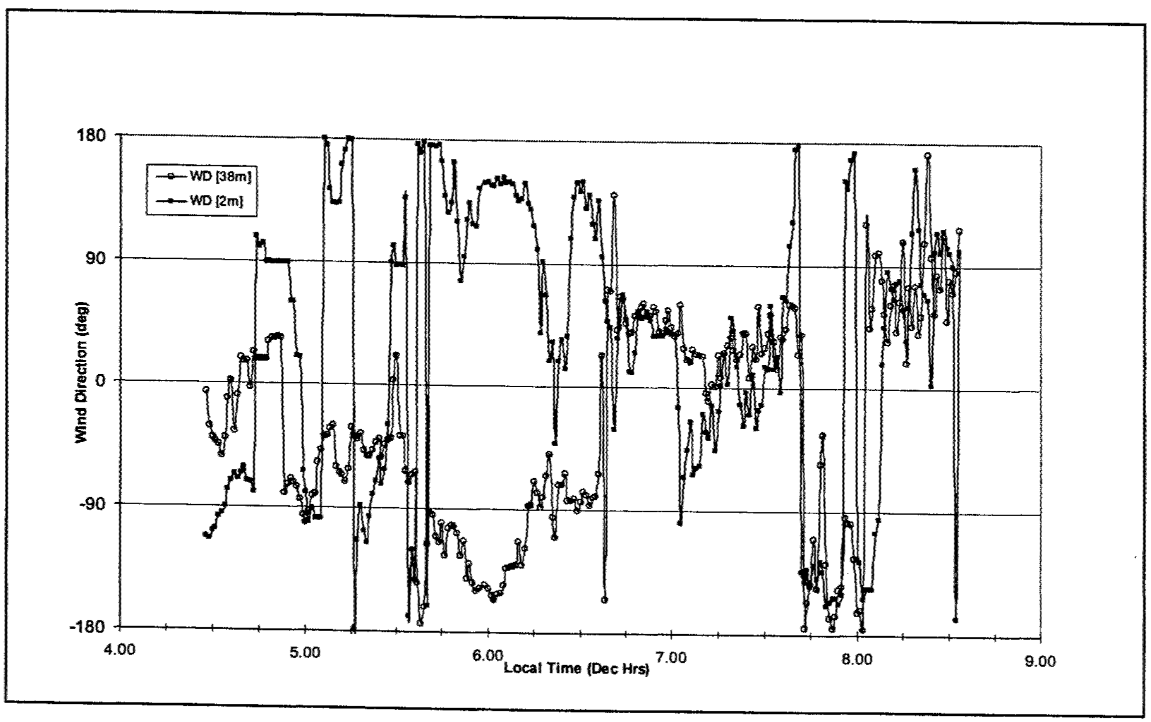

Figure A28. Thompson Tower-2001 March 22: Wind Direction.

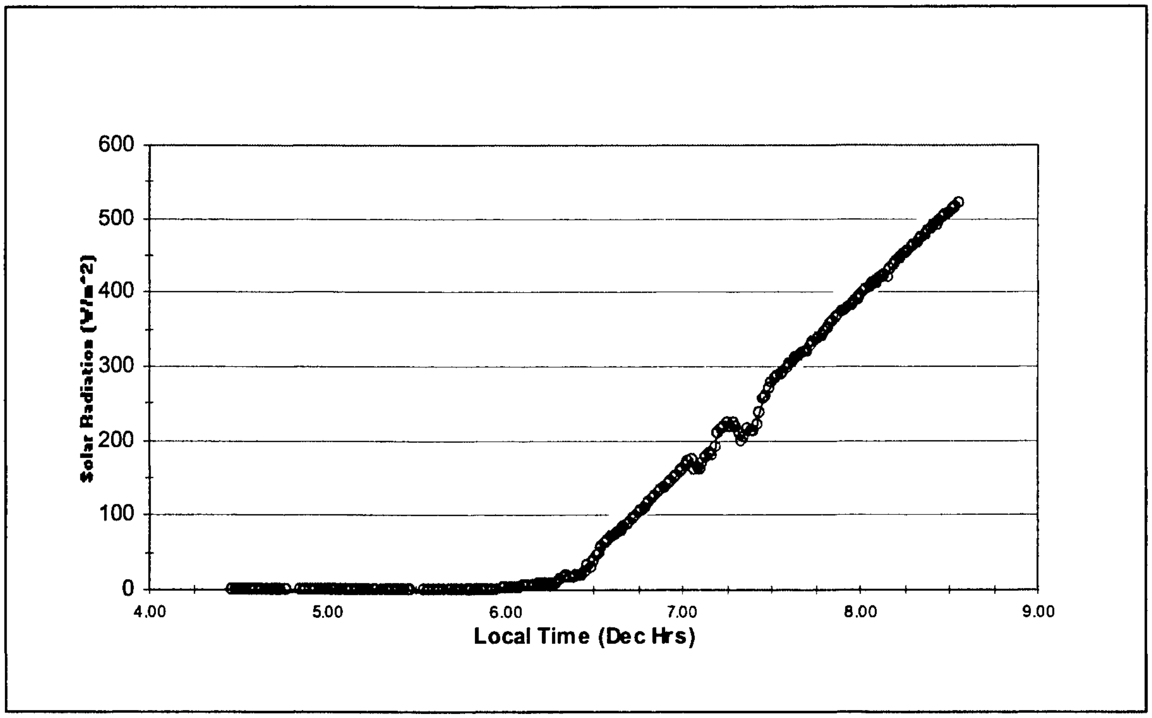

Figure A29. Thompson Tower-2001 March 22: Solar Radiation.

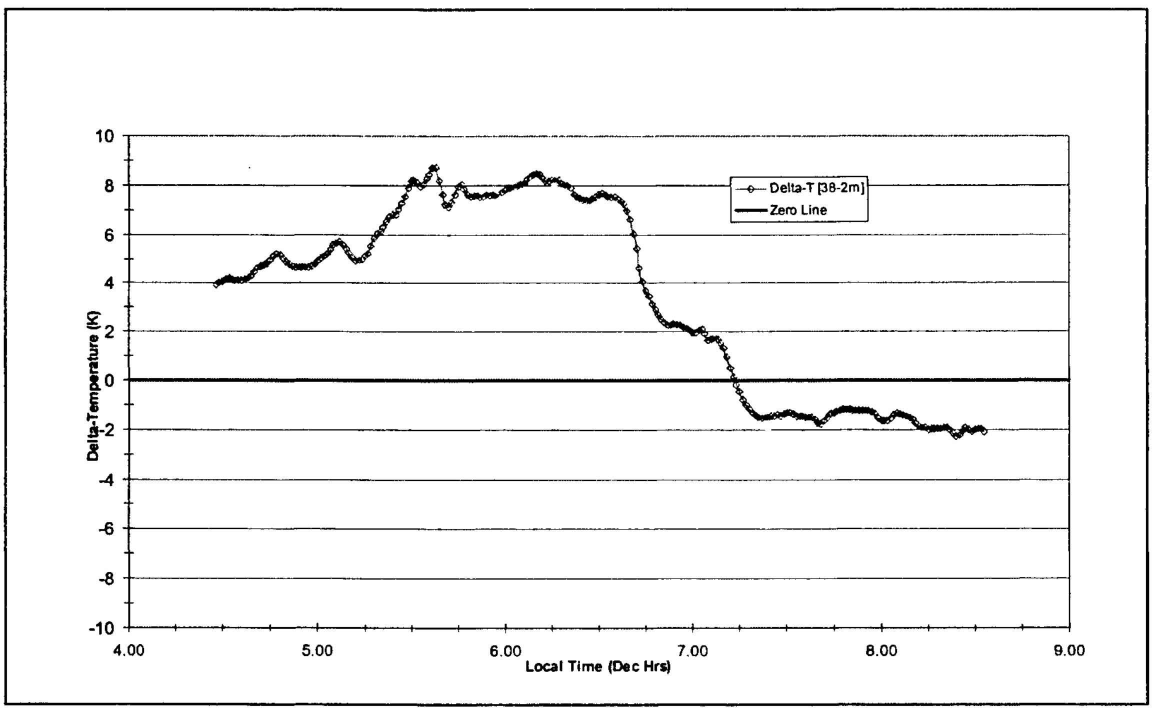

Figure A30. Thompson Tower-2001 March 22: Delta-T.

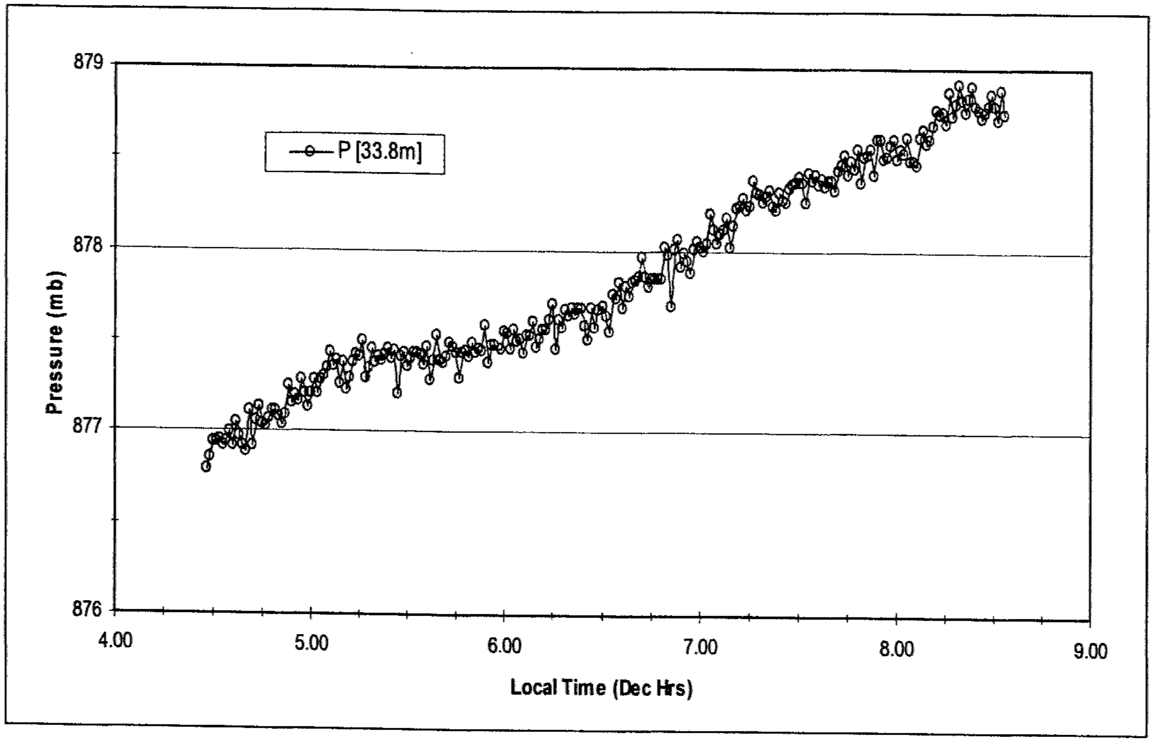

Figure A31. Thompson Tower-2001 March 22: Pressure.

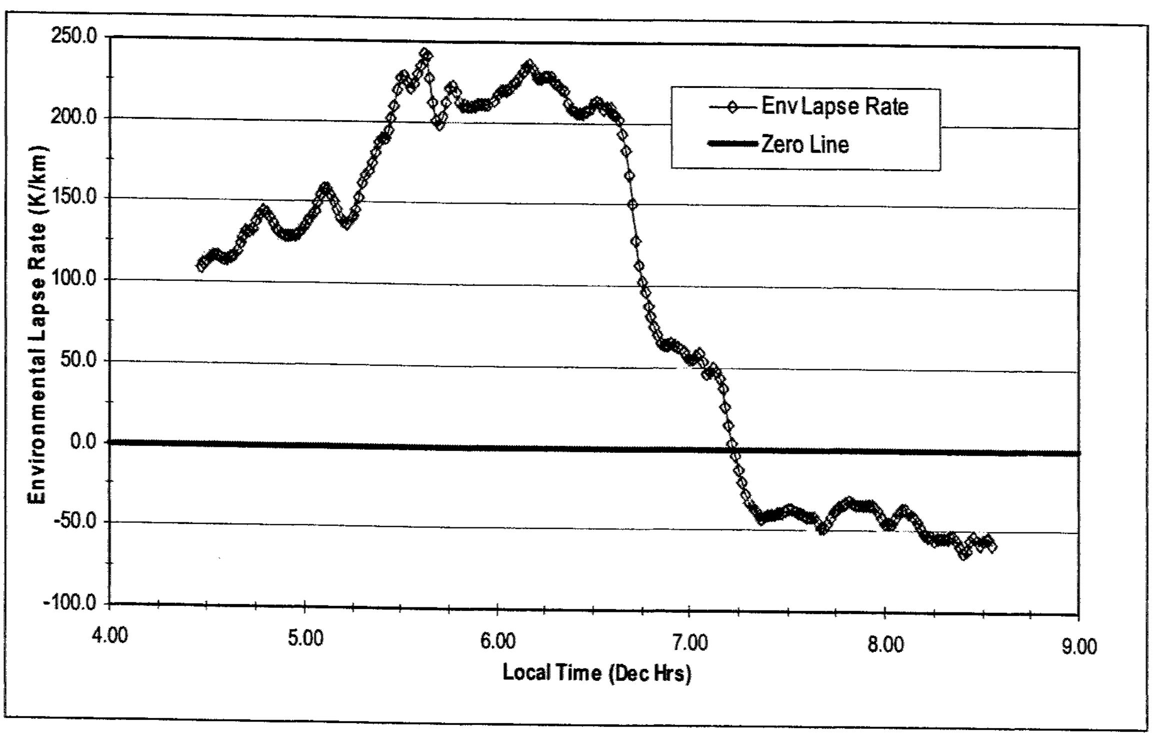

Figure A32. Thompson Tower-2001 March 22: ELR.

Appendix B. Rawinsonde Data

This appendix is part of ARL-TR-2798, Surface Layer Stability Transition Research Minimum Time Delay from Sunrise: 2001 March Case Study, U.S. Army Research Laboratory, White Sands Missile Range, NM 88002-5501.

A quasi-Lagrangian (following the parcel) perspective on the atmospheric conditions during the Nighttime (Stable) to Daytime (Unstable) transition was quantitatively recorded by the Thompson Tower site Rawinsonde (RAOB) data. The RAOB data, referenced as 'C-station,' were released at the White Sands Missile Range Desert Site (about 5 miles northeast of Thompson Tower). A full day's worth of data is presented on a single plot. The earliest Sub-case (Stable) is designated with a red solid box. An orange open circle shows the Neutral Sub-case. The Unstable Sub-case is a green solid triangle, and any additional Unstable data is a blue open diamond. We have purposefully elected to follow the rainbow's spectrum to make data viewing easier. As a reminder, the general times designated for each Sub-case were:

Stable	0500–0600 MST
Neutral	0630–0730 MST
Unstable	0800–0830 MST

The 1540 MST Pre-Test data flight on 2001 March 19 was included for completeness. The following are the four sections of Appendix B:

- Figures B1–B6: 2001 March 19
- Figures B7–B12: 2001 March 20
- Figures B13–B18: 2001 March 21
- Figures B19–B22: 2001 March 22

Figures B1–B6: 2001 March 19-Rawinsonde Data

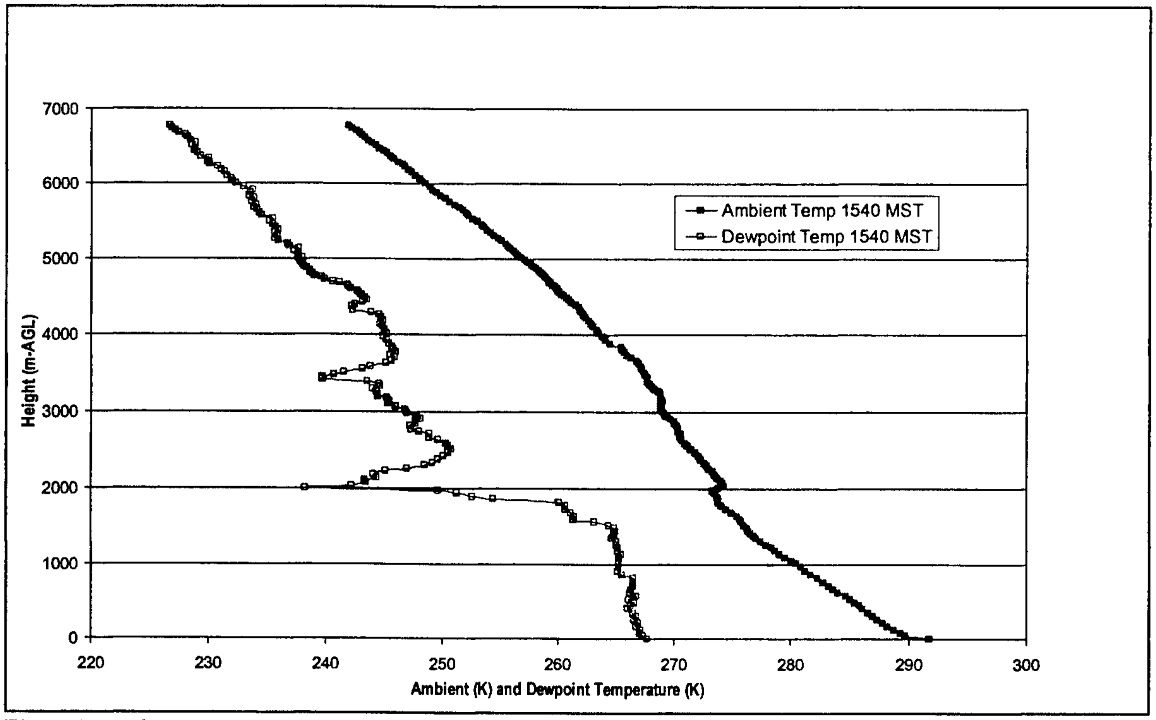

Figure B1. Thompson Tower RAOB Launch-2001 March 19: Temperature.

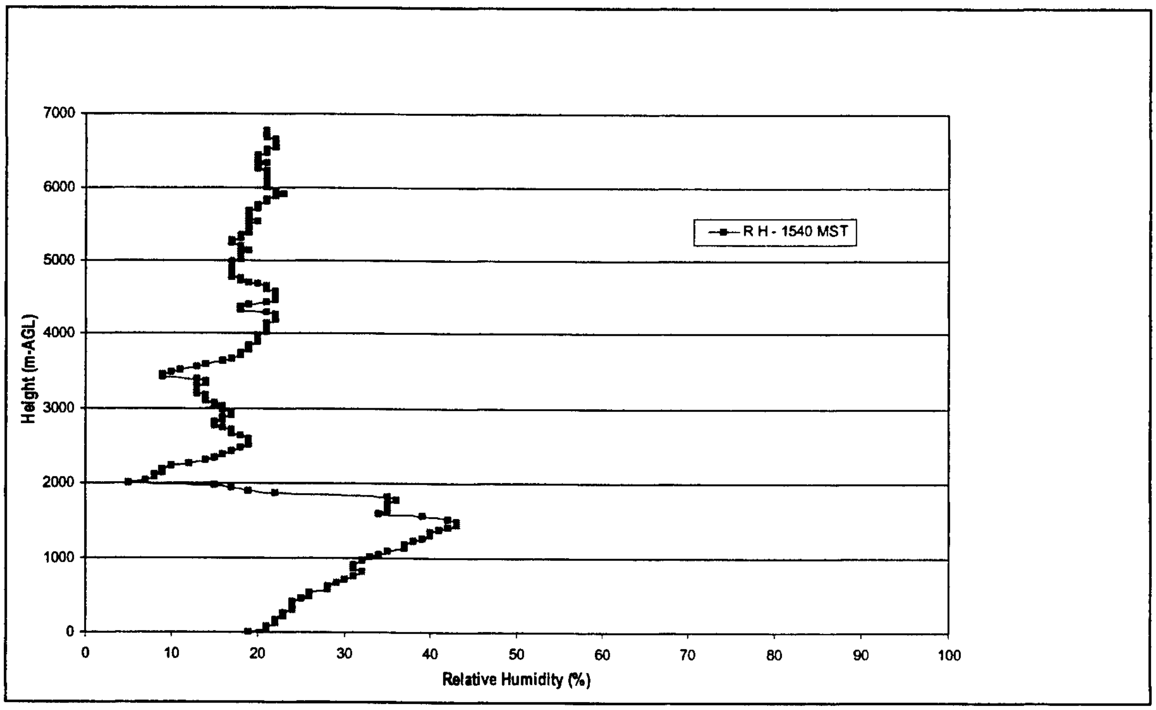

Figure B2. Thompson Tower RAOB Launch-2001 March 19: Relative Humidity.

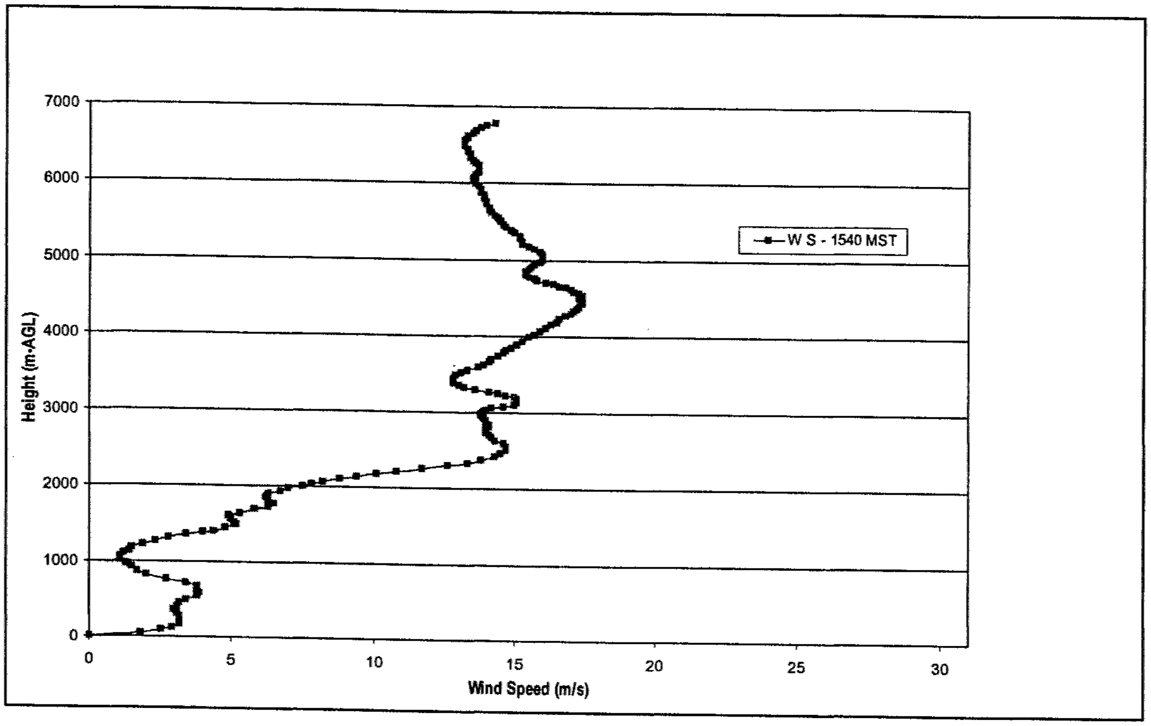

Figure B3. Thompson Tower RAOB Launch-2001 March 19: Wind Speed.

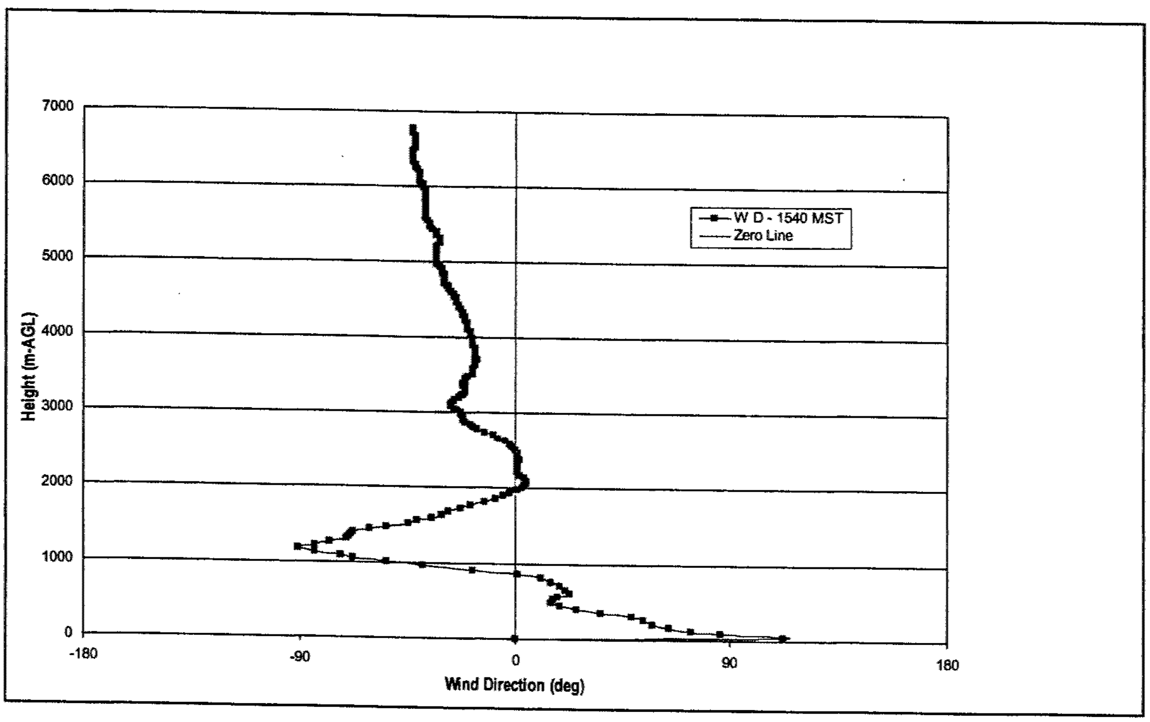

Figure B4. Thompson Tower RAOB Launch-2001 March 19: Wind Speed.

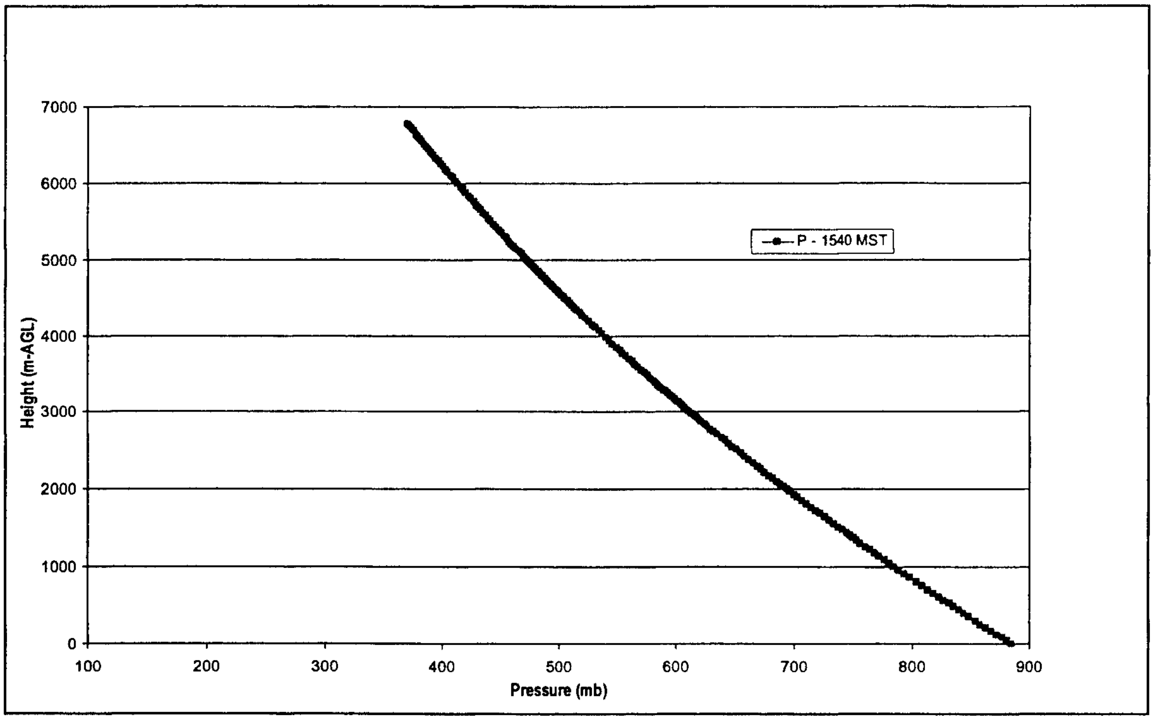

Figure B5. Thompson Tower RAOB Launch-2001 March 19: Pressure.

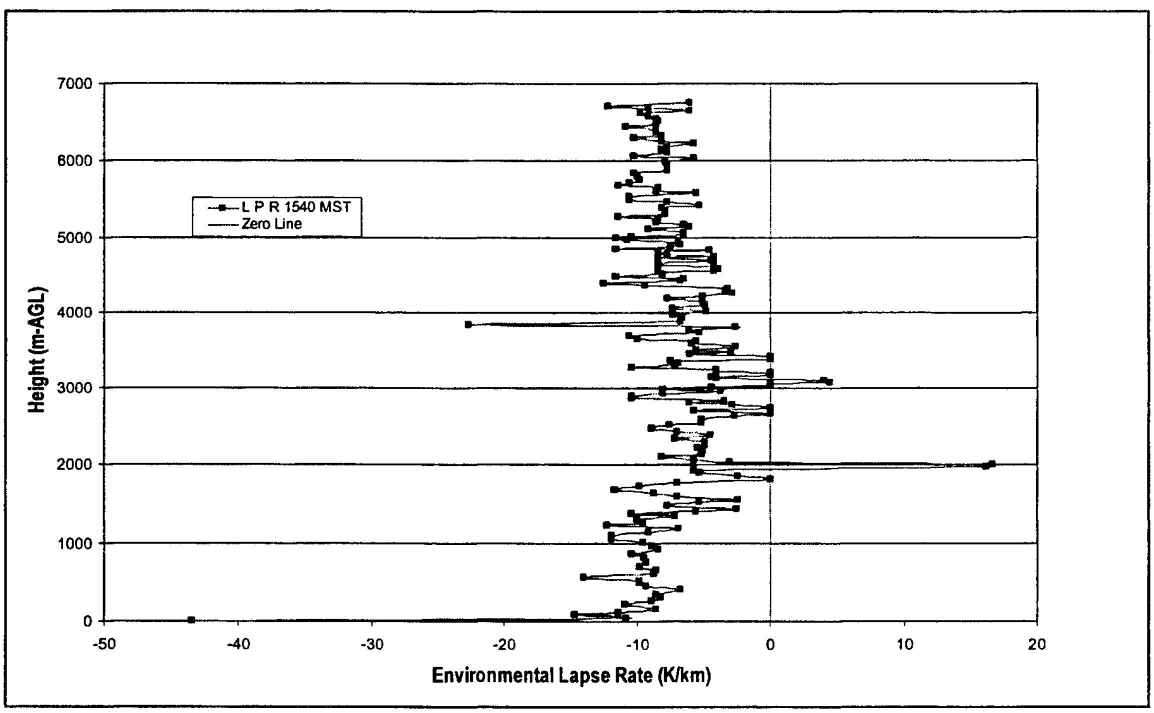

Figure B6. Thompson Tower RAOB Launch-2001 March 19: ELR.

Figures B7–B12: 2001 March 20-Rawinsonde Data

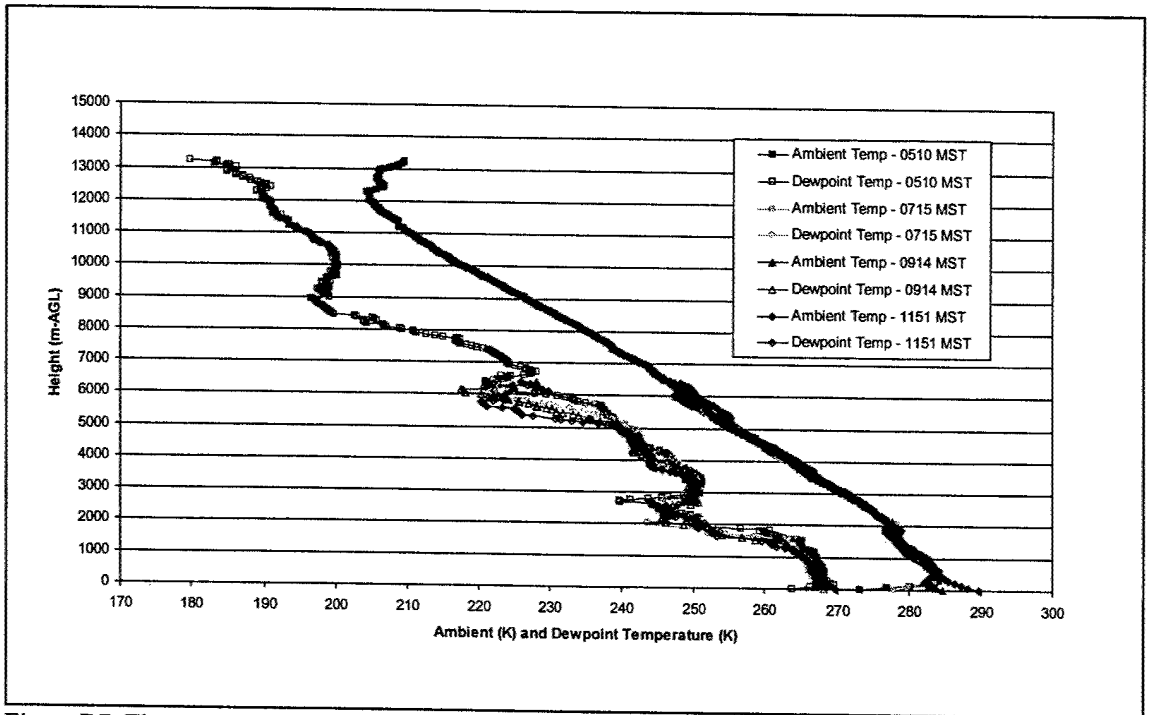

Figure B7. Thompson Tower RAOB Launch-2001 March 20: Temperature.

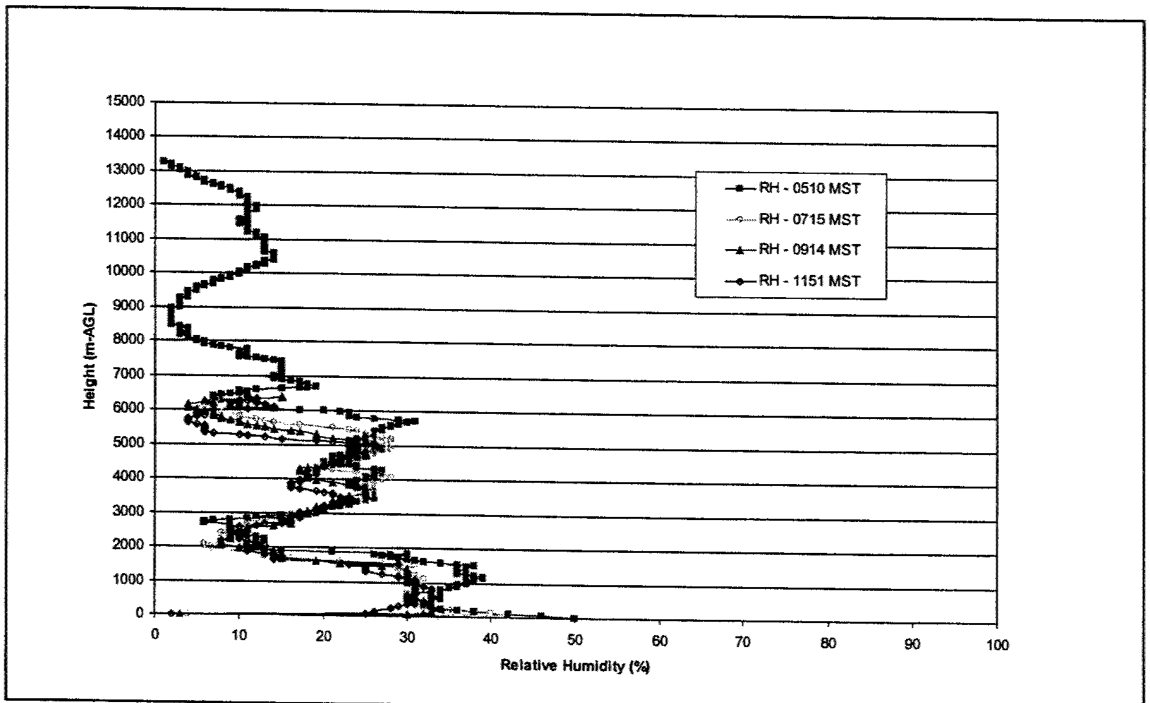

Figure B8. Thompson Tower RAOB Launch-2001 March 20: Relative Humidity.

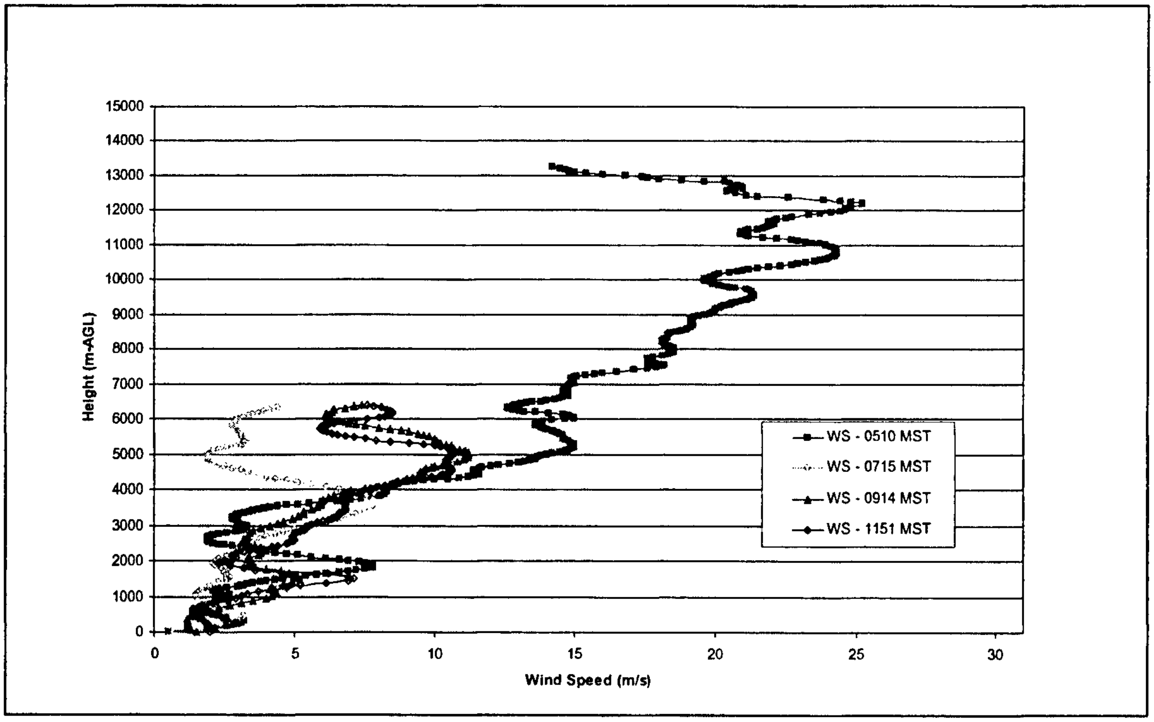

Figure B9. Thompson Tower RAOB Launch-2001 March 20: Wind Speed.

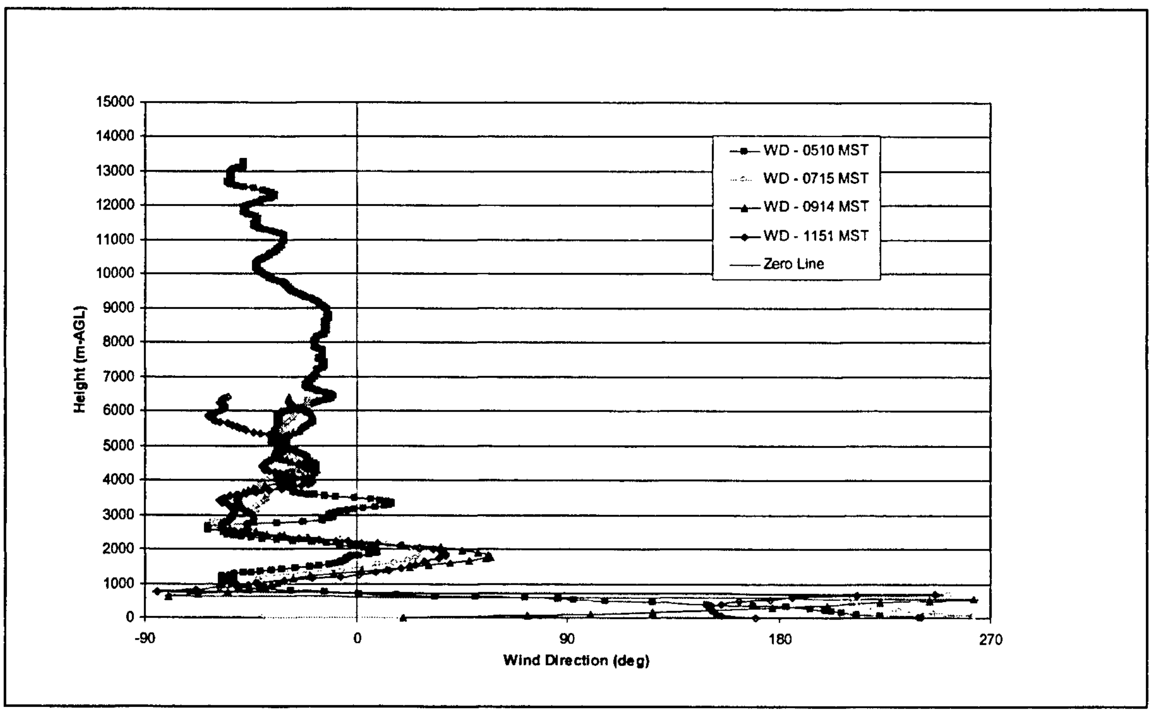

Figure B10. Thompson Tower RAOB Launch-2001 March 20: Wind Direction.

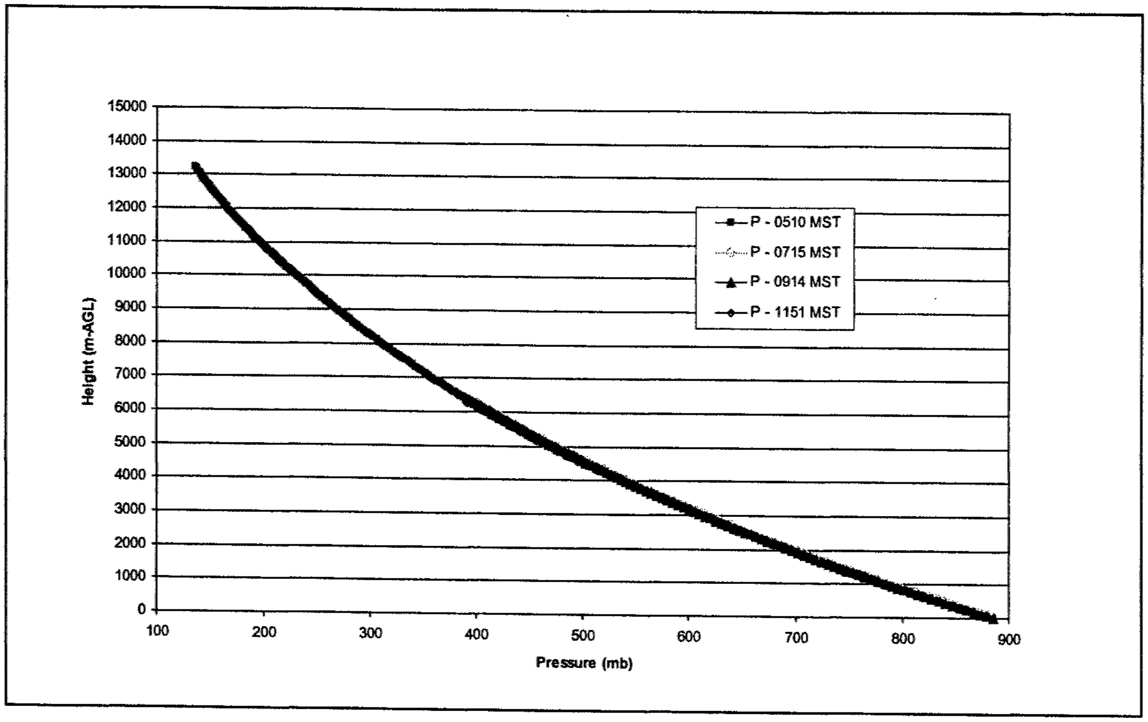

Figure B11. Thompson Tower RAOB Launch-2001 March 20: Pressure.

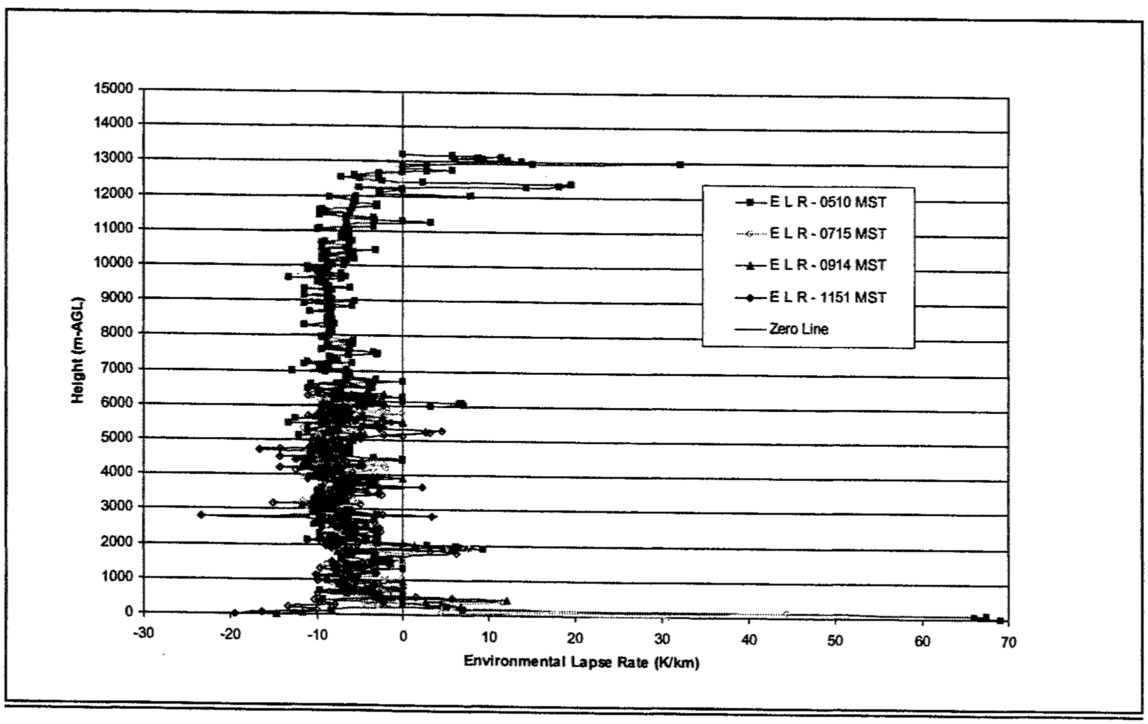

Figure B12. Thompson Tower RAOB Launch-2001 March 20: ELR

Figures B13–B18: 2001 March 21-Rawinsonde Data

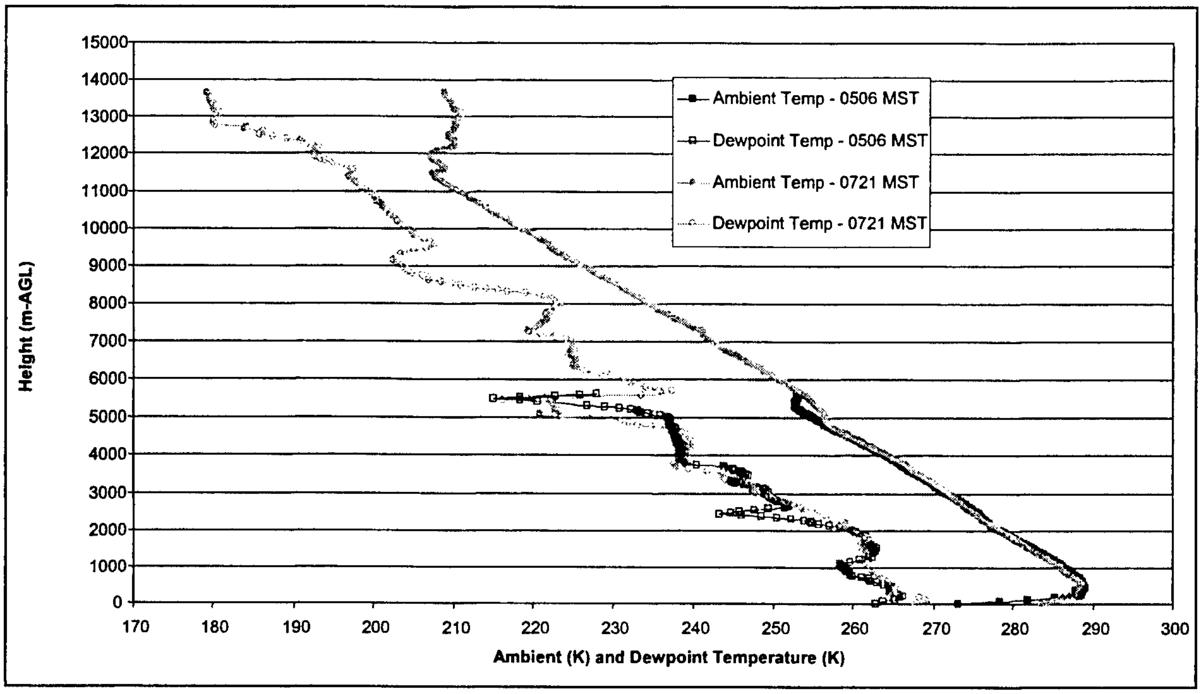

Figure B13. Thompson Tower RAOB Launch-2001 March 21: Temperature.

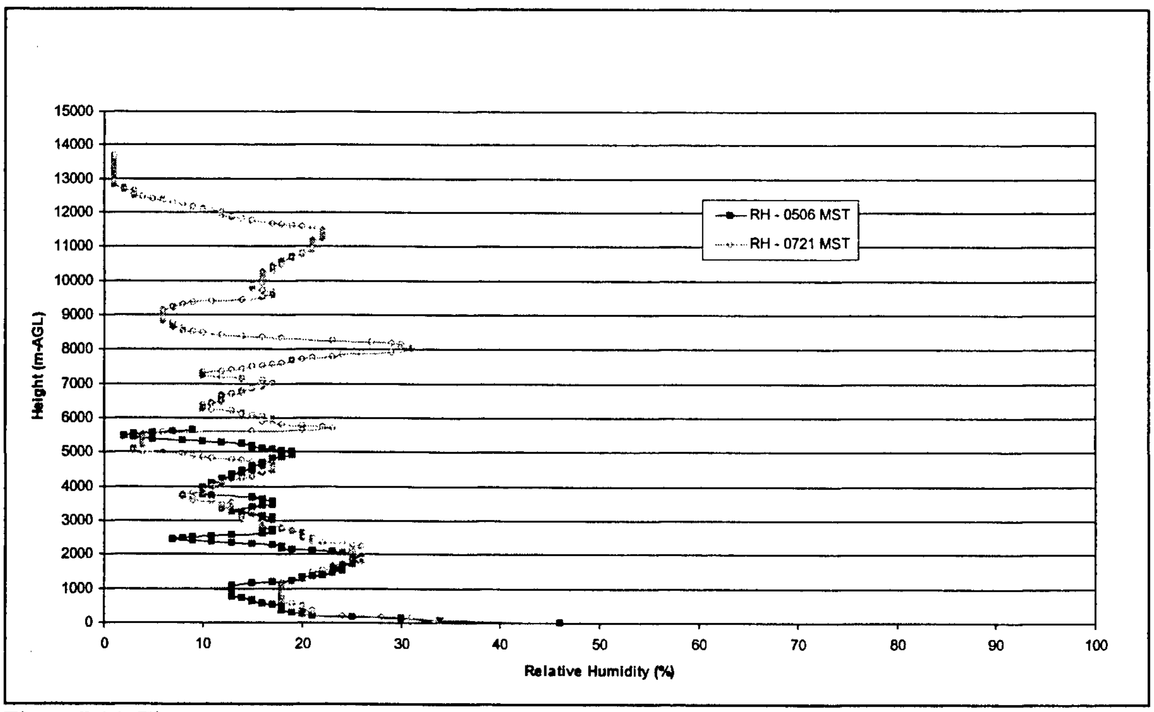

Figure B14. Thompson Tower RAOB Launch-2001 March 21: Relative Humidity.

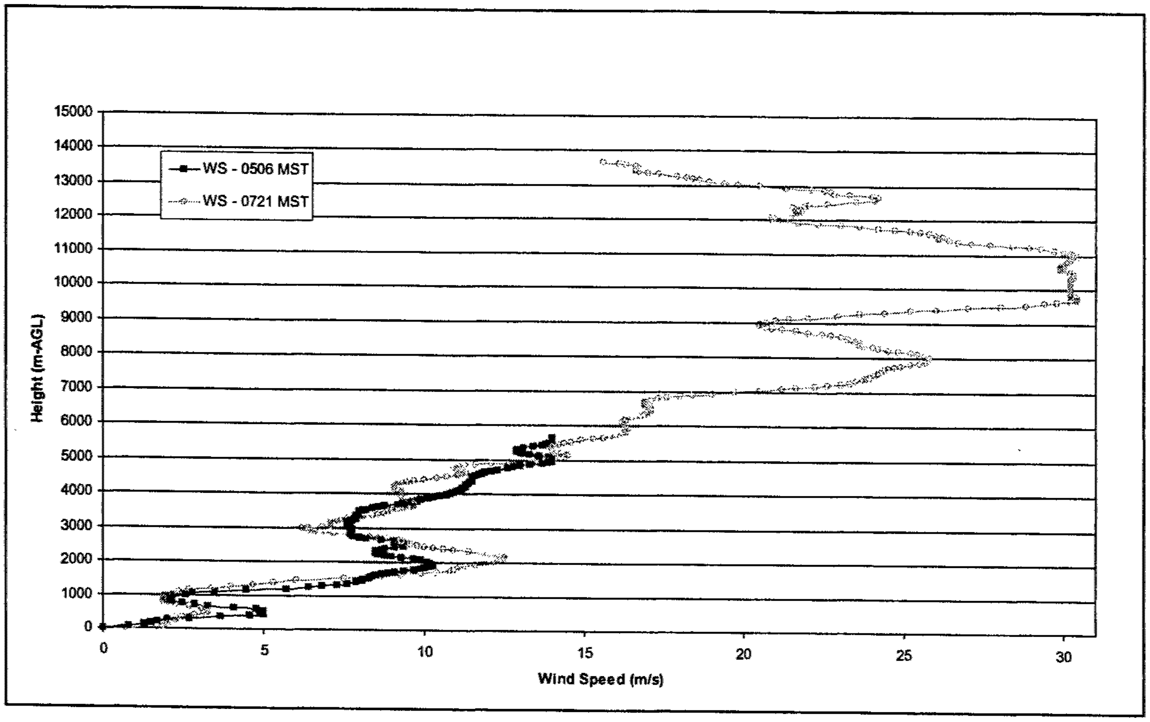

Figure B15. Thompson Tower RAOB Launch-2001 March 21: Wind Speed.

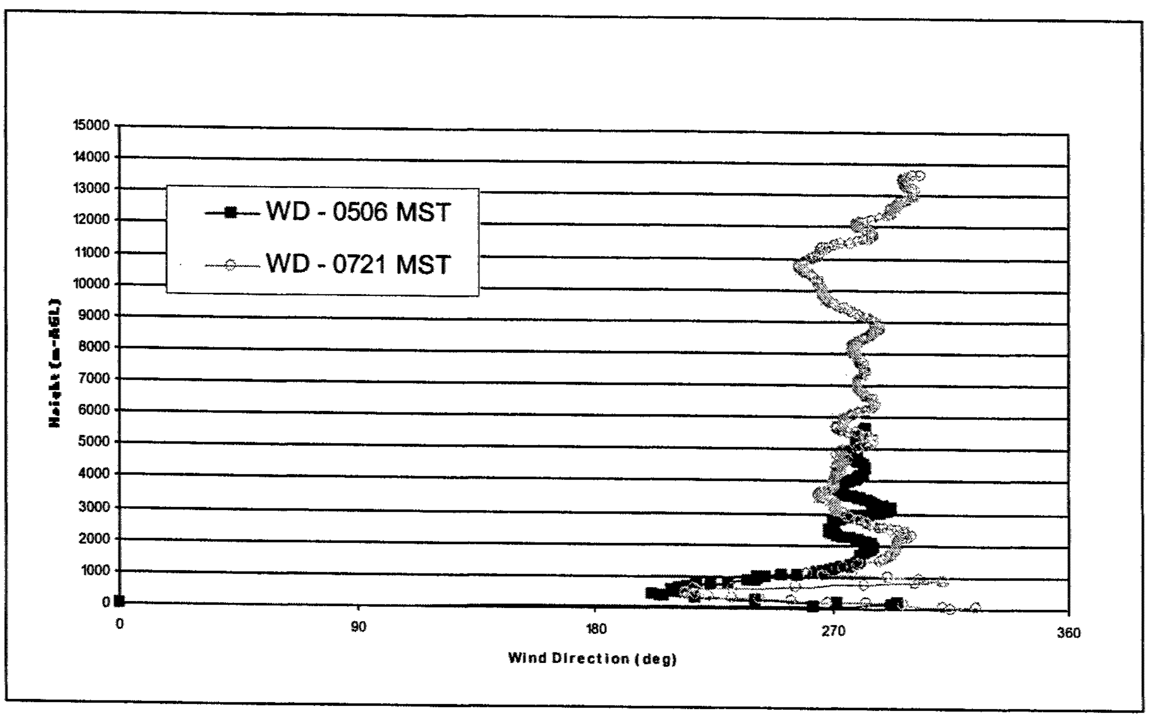

Figure B16. Thompson Tower RAOB Launch-2001 March 21: Wind Direction.

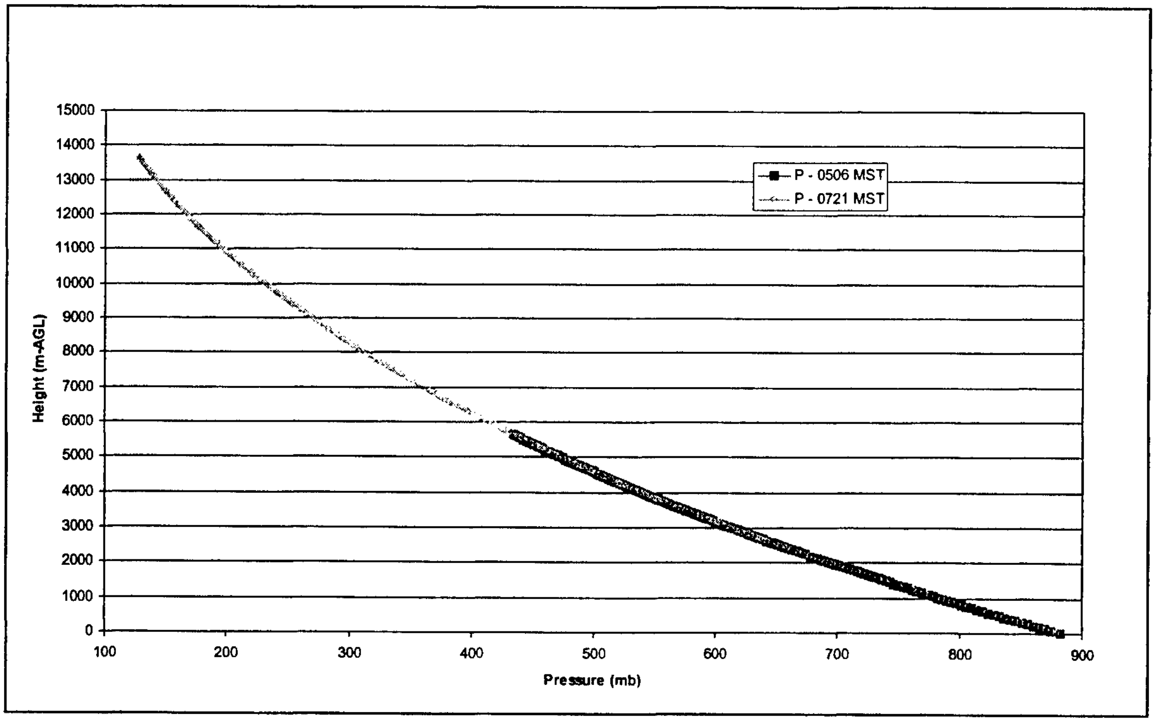

Figure B17. Thompson Tower RAOB Launch-2001 March 21: Pressure.

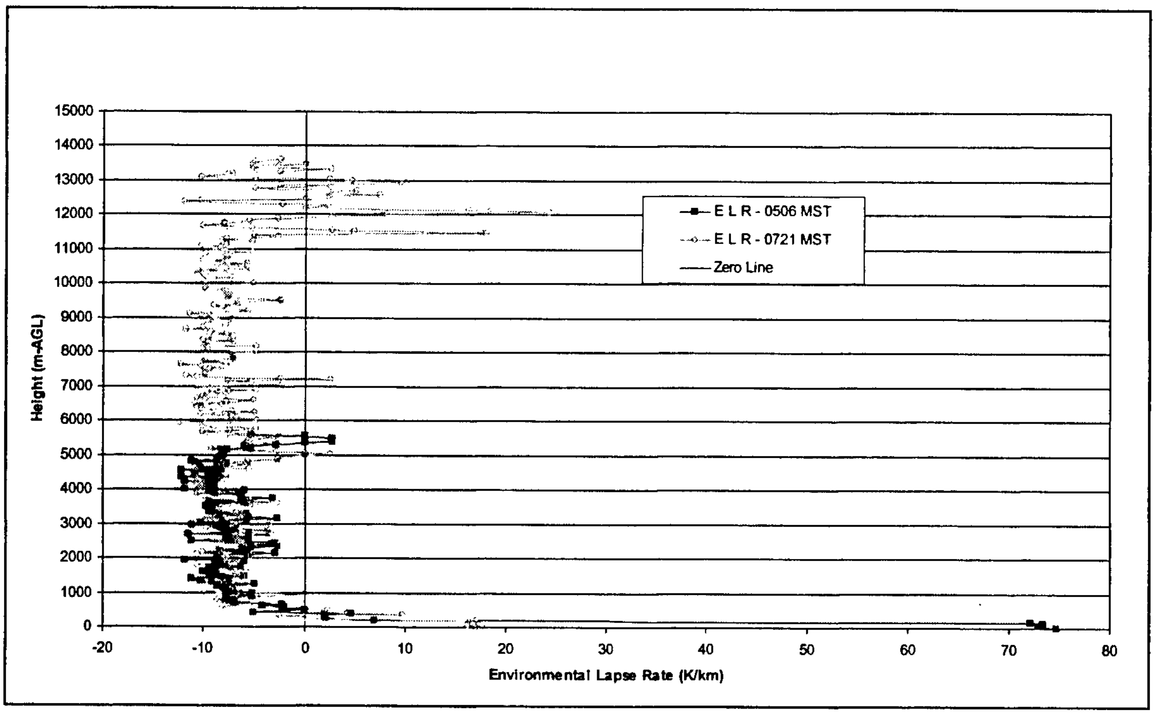

Figure B18. Thompson Tower RAOB Launch-2001 March 21: ELR.

Figures B19–B22: 2001 March 22-Rawinsonde Data

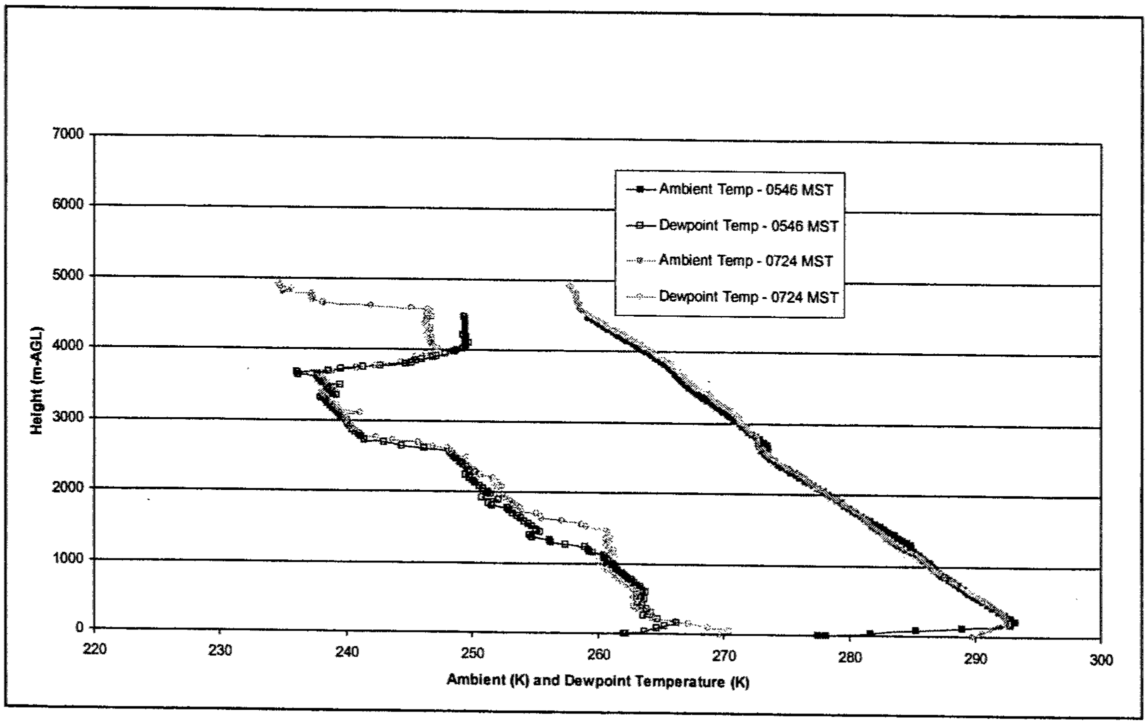

Figure B19. Thompson Tower RAOB Launch-2001 March 22: Temperature.

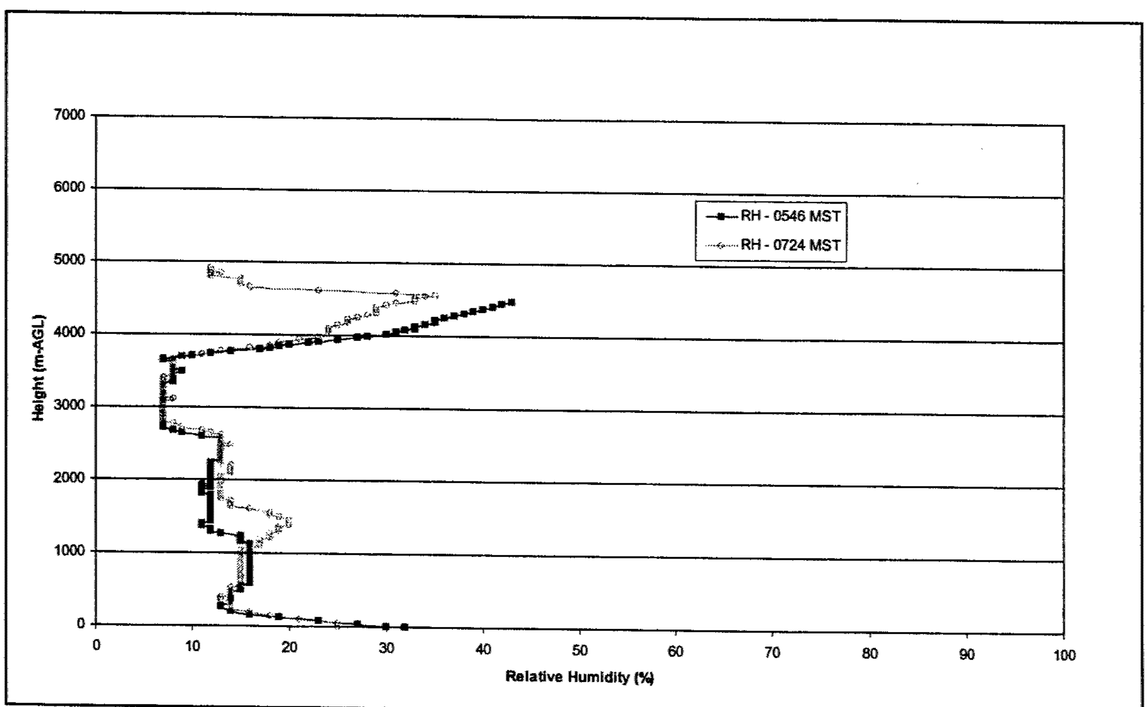

Figure B20. Thompson Tower RAOB Launch-2001 March 22: Relative Humidity.

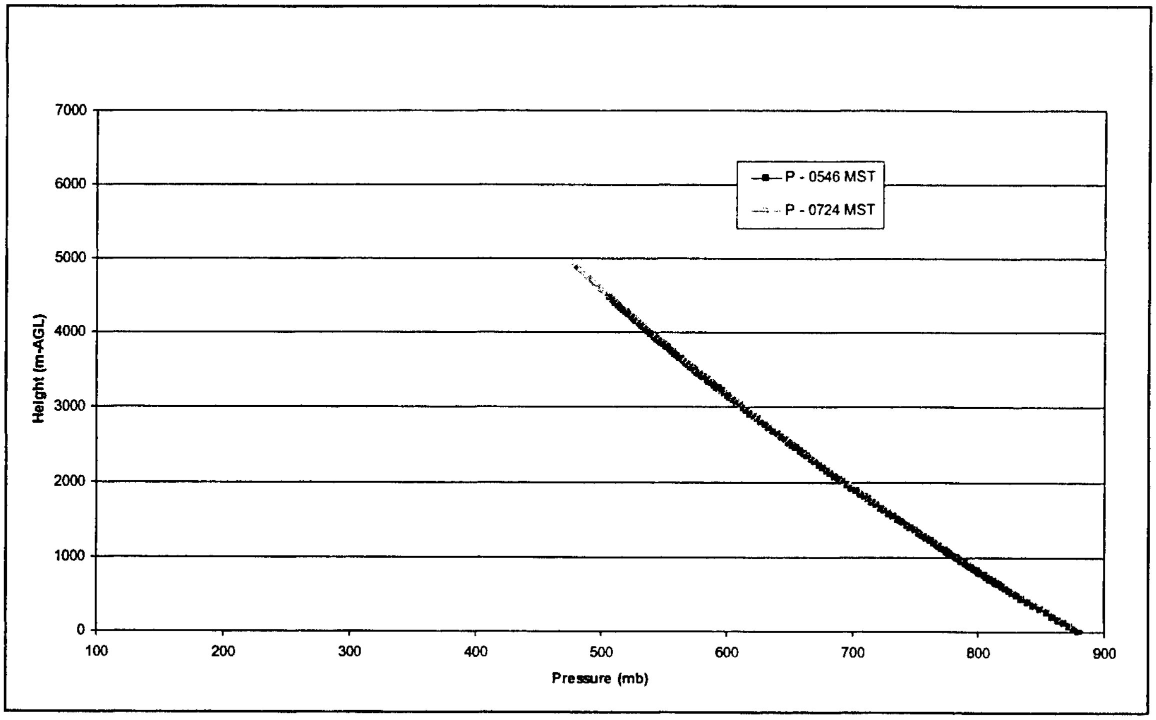

Figure B21. Thompson Tower RAOB Launch-2001 March 22: Pressure.

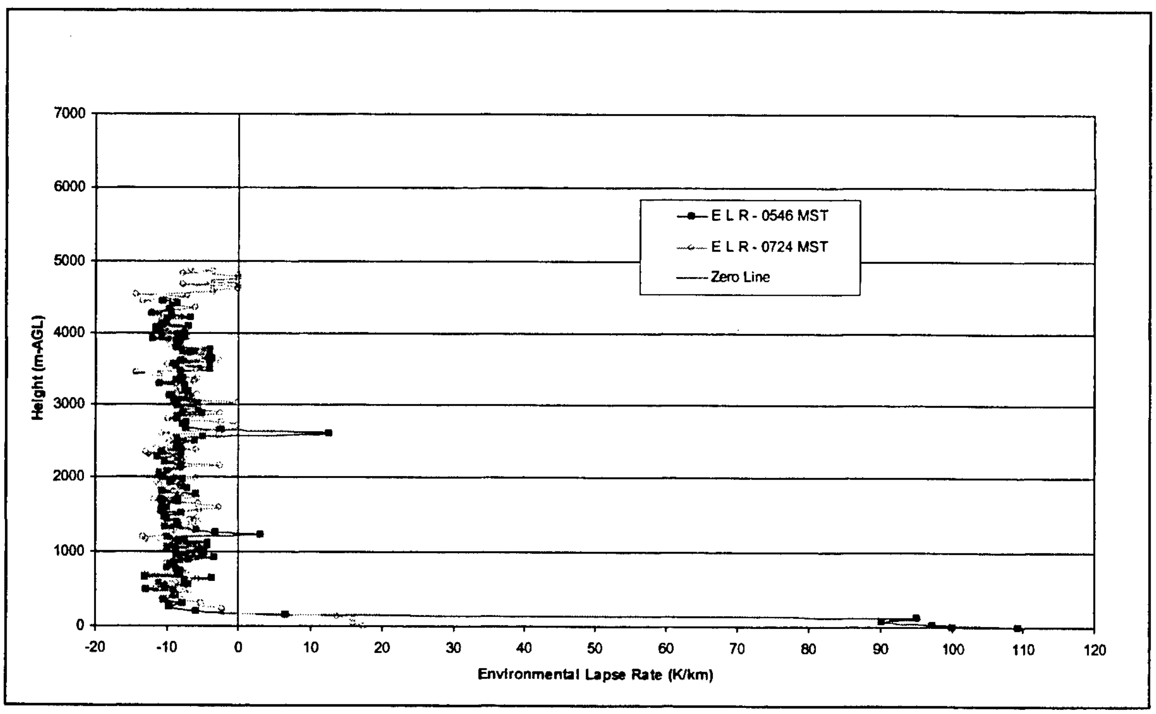

Figure B22. Thompson Tower RAOB Launch-2001 March 22: ELR.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Near surface target acquisition and EO propagation significantly improve during the Surface Layer Stability Transition (SLST). Thus, this research expands Army Chief of Staff Shinseki's vision from "to see first" to, "to see better." The SLST is also the starting and ending points for the atmospheric convection growth phase, an important factor in chemical warfare modeling.

In 2001, the Meteorological-sensors Integration Team of the Army Research Laboratory conducted the first of three field tests with the primary purpose of characterizing, modeling and exploiting repeatable patterns in the lower portion of the atmospheric boundary layer. The repeatable patterns investigated were the morning Stability Transitions (ST) or Neutral Events (NE). The 2001 March 20–22 test dates were selected based on a forecasted minimal time interval between the local Sunrise and an Ideal case NE. Two subsequent field tests addressed the maximum (June) and a second minimum (September) Sunrise-to-NE time interval. These latter Tests are documented separately.

The Surface Layer Stability Transition research pursued two measurement and analysis methods: Eulerian (Tower data) and quasi-Lagrangian (Rawinsonde data). The results included validation data for the Ideal Neutral Event Forecast Model and a characterization of a desert stable-neutral-unstable morning transition over the Equinox time period. The information documented here serves as a useful building block in support of the primary goal.

15. SUBJECT TERMS

Stability Transition, Neutral Events, Delta-T, Lapse Rate

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